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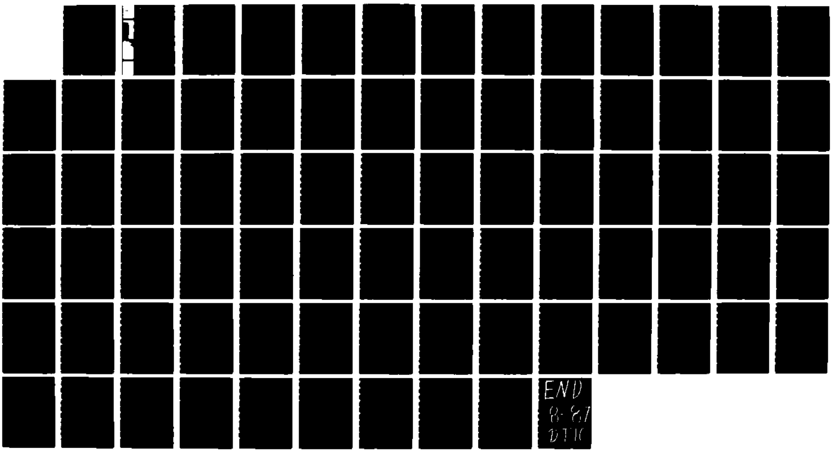

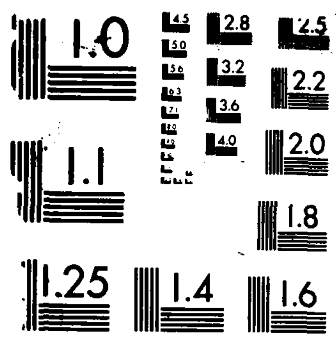

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CHANNEL DEVELOPMENT IN THE LOWER REACH OF THE RED RIVER

Hydraulic Model Investigation

by

J. E. Foster, C. R. O'Dell, J. E. Glover

Hydraulics Laboratory

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US ARMY ENGINEER WATERWAYS EXPERIMENT STATION

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19 ABSTRACT (Continue on reverse if necessary and identify by block number)

The Red River Waterway provides for the development of a 9-ft-deep by 200-ft-wide navigation channel from Lake of Pines near Daingerfield, Texas, to Old River. The lower reach of the Red River with its flat slopes and narrow bends [illegible] short radii transverses the flood plain of the Mississippi River. A movable-bed model, reproducing about [illegible] miles of the Red River and a short section of the Black River to a horizontal scale of 1:120 and a vertical scale of 1:80, was used to provide [illegible] maintenance dredging that would be required to: (a) maintain a navigation [illegible] from Lock and Dam 1 to Old River, (b) develop a system of channel training structures [illegible] minimize the required dredging, and (c) determine the ultimate [illegible] cutoff, a cutoff proposed just upstream [illegible] The results of this investigation revealed:

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8a. NAME OF FUNDING/SPONSORING ORGANIZATION (Continued).

US Army Engineer District,
New Orleans

19. ABSTRACT (Continued).

a. The proposed overall channel was too wide to maintain a navigation channel of adequate width and depth above the Black River.

b. The development of an adequate navigation channel in the test reach would require a reduction in the width of the overall channel. This can be obtained with dikes or by moving the banks closer together and revetting them.

c. The first of the two plans proposed by the US Army Engineer District, New Orleans, Plan A, consisted of a 1.9-mile cutoff from mile 36.5 to 34.3 to increase the radius of the bend at the mouth of the Black River and the radius of the next bend upstream. Plan B was similar to Plan A in that it consisted of a cutoff channel in the same area; however, the cutoff channel for Plan B was 0.2 mile longer, and contained curves with radii at least 2,400 ft longer. Plan B, with its longer radius curves, would require less dike construction than Plan A to develop a navigation channel.

d. Structures would be required on the left bank downstream of the Black River to develop an adequate channel along an alignment suitable for navigation.

e. Structures would be required on the downstream entrance to the old bendway to maintain an access channel into the old bendway for recreation.

PREFACE

The model investigation reported herein was requested by the US Army Engineer District, New Orleans (LMN), in letter of 8 March 1972 from LMN to the US Army Engineer Waterways Experiment Station (WES), subject: Red River Waterway, Lock and Dam No. 1, Model Study. The study was conducted during the period March 1972 to November 1978. The US Army Engineer Division, Lower Mississippi Valley (LMVD), and LMN were informed of the progress of the study through progress reports and periodic transmittal of preliminary results. In addition, representatives from LMVD and LMN visited WES during the course of the study to observe special tests and discuss test results.

At the time of this investigation in the Hydraulics Laboratory, the work was conducted under the general supervision of Messrs. H. B. Simmons as Chief, with F. A. Herrmann, Jr. as Assistant Chief, and under the direct supervision of Messrs. J. E. Glover, Chief of the Waterways Division, and J. J. Franco, retired Chief. The engineer in immediate charge of the model study was Mr. J. E. Foster, retired Chief of the River Regulation Branch. He was assisted by Messrs. C. R. O'Dell, J. A. Holliday, and A. J. Cook. This report was prepared by Mr. Foster. His efforts were supported by Mr. O'Dell's preparation of preliminary data and Mr. Glover's review. Editing was done by Mrs. Gilda Miller and the coordination of text and figure layout was done by Ms. Debby Shiers, Information Products Division, Information Technology Laboratory, WES.

COL Allen F. Grum, USA, was the previous Director of WES. COL Dwayne G. Lee, CE, is the present Commander and Director. Dr. Robert W. Whalin is Technical Director.

CONTENTS

CONVERSION FACTORS, NON-SI TO SI (METRIC)
UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
degrees (angle)	0.01745329	radians
feet	0.3048	metres
cubic feet per second	0.02831685	cubic metres per second
miles (US statute)	1.609347	kilometres

A-1

CHANNEL DEVELOPMENT IN THE LOWER REACH OF THE RED RIVER

Hydraulic Model Investigation

PART I: INTRODUCTION

Location and Description of Prototype

1. The Red River (Figure 1) flows easterly from the northwest portion of Texas, along the border between Texas and Oklahoma into southwestern Arkansas where it turns southerly into northwestern Louisiana to Shreveport, then southeasterly through northern Louisiana to Alexandria, then easterly to join the Old River and form the Atchafalaya River. The Atchafalaya River flows through the southeastern portion of Louisiana to the Gulf of Mexico downstream of Morgan City. Flow in the upper portion of the Red River is controlled by releases from Denison Dam, which is located on the Texas-Oklahoma state line. Flows from the Mississippi River through Old River Diversion Canal have considerable backwater effect on stages in the lower portion of the Red River. A 75-ft* by 1,200-ft lock at the mouth of Old River provides for navigation between the Mississippi and Red-Atchafalaya Rivers.

2. The Red River is characterized by large fluctuations in stage, shifting bed and banks, and unpredictable shoaling. From Alexandria to Old River, the Red River with its flat slope and low banks traverses the flood plain of the Mississippi River. The water-surface slope in this reach is dependent not only upon the flow in the Red River but also the flow in the Black River and the backwater effect of flows from the Mississippi River through Old River Diversion Canal. Due to long periods of low flow, narrow bends of short radii, and a heavy sediment load, the use of the Red River for movement of cargo by barges has been limited.

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* A table of factors for converting non-SI units of measurement to SI (metric) units is presented on page 3.

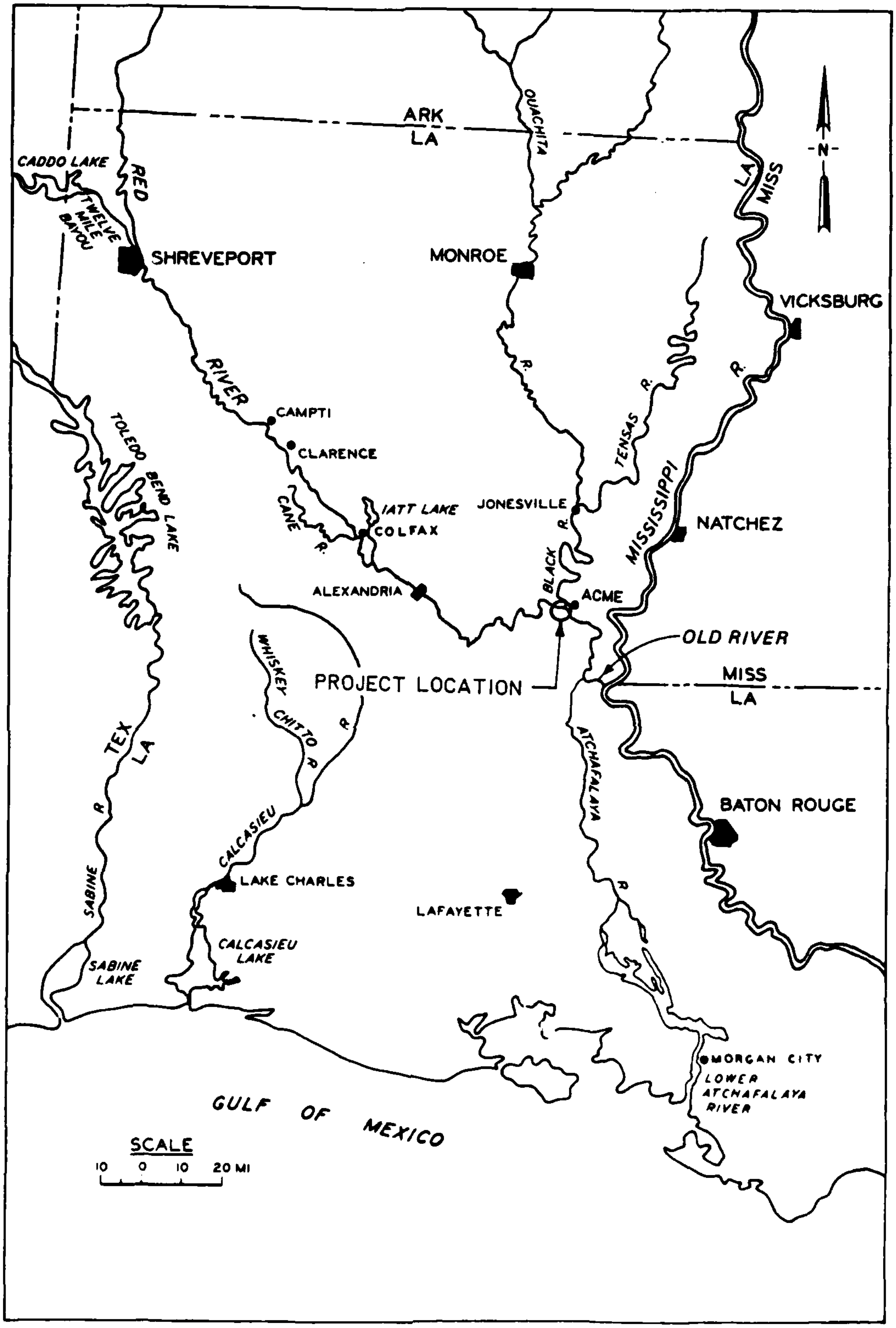


Figure 1. Location map

Plan of Development

3. The 90th Congress authorized the development of the Red River Waterway with the passage of Public Law 90-483 on 13 August 1968. As presently authorized, the project provides for the improvement of the Red River and its tributaries into Louisiana, Arkansas, Texas, and Oklahoma through coordinated development for navigation, bank stabilization, flood control, recreation, fish and wildlife, and water-quality control. The primary function of the project is to provide for the establishing of a 9-ft-deep by 200-ft-wide navigation channel from Old River to Lake of Pines near Daingerfield, Texas, by a system of nine locks and dams, extensive channel realignment, a number of cutoffs, and miles of channel training and stabilization works. The project consists of four distinct reaches: (a) Mississippi River to Shreveport, Louisiana; (b) Shreveport to Daingerfield, Texas; (c) Shreveport to Index, Arkansas; and (d) Index to Denison Dam, Texas. The Appropriations Act of 1971, approved 7 October 1970, as Public Law 91-439, provided authority to initiate preconstruction planning in the Mississippi River-to-Shreveport Reach, the only reach pertinent to this study.

Need for and Purpose of Model Study

4. The development of the lower reach of the Red River for navigation will require the solution to many channel development and maintenance problems. Analytical solutions to these problems on a river heavily laden with sediment are complex and uncertain. Therefore, it was decided that this hydraulic movable-bed model be used to determine some of the problems involved, develop some solutions to these problems, and accumulate some general information that can be used in the solution to problems in other reaches. The specific purposes of this investigation were: (a) to provide an indication of the amount of maintenance dredging that would be required to maintain a navigation channel from Lock and Dam 1 to Old River; (b) to determine the optimum alignment and ultimate channel section to be expected in Lorran Lake cutoff (a proposed cutoff just upstream of the mouth of the Black River); and (c) to develop a system of channel structures that would minimize the required dredging in this reach.

PART II: THE MODEL

Description

5. The model (Figure 2) reproduced 4.7 miles of the Red River (from mile 37.5* to 32.8), a short section of the Black River, and the adjacent overbank areas to a distorted scale of 1:120 horizontally and 1:80 vertically. A small supplemental slope, needed to provide satisfactory bed movement, was incorporated in the model design. The model was of the movable-bed type with the banks and overbank areas molded in sand-cement mortar. The bed was molded in crushed coal with a median grain diameter of about 4 mm and a specific gravity of 1.30. Dikes were molded of crushed stone. Folded strips of wire mesh were used to simulate the roughness effect of trees and underbrush on the overbank areas.

6. Initially, the model channel bed was molded to configurations indicated by the prototype hydrographic survey of March 1968, as shown in Plate 1. Overbank areas were molded to the contours and elevations indicated by the latest available maps and charts.

Appurtenances

7. Water was supplied to the model by a 10-cfs axial flow pump in a circulating system. Discharge was controlled and measured by valves and venturi meters at the upper end of the model on the Red and Black Rivers. Water-surface elevations along the channel were measured by nine point gages, as shown in Figure 2. Water-surface elevations of the lower end of the model were controlled with an adjustable tailgate. A graduated container was used to measure bed material introduced at the upper end of the model. A sediment trap was provided at the lower end of the model where extruded material could accumulate and be measured to determine the amount discharged for any period. A carefully graded rail was installed along each side of the channel to support sheet metal templets used for molding the model bed prior to initiation of certain tests. These rails were also used to provide vertical control for

* All mileage cited herein refers to 1967 river miles above Old River. For test conditions, the mileage is measured through the cutoff.

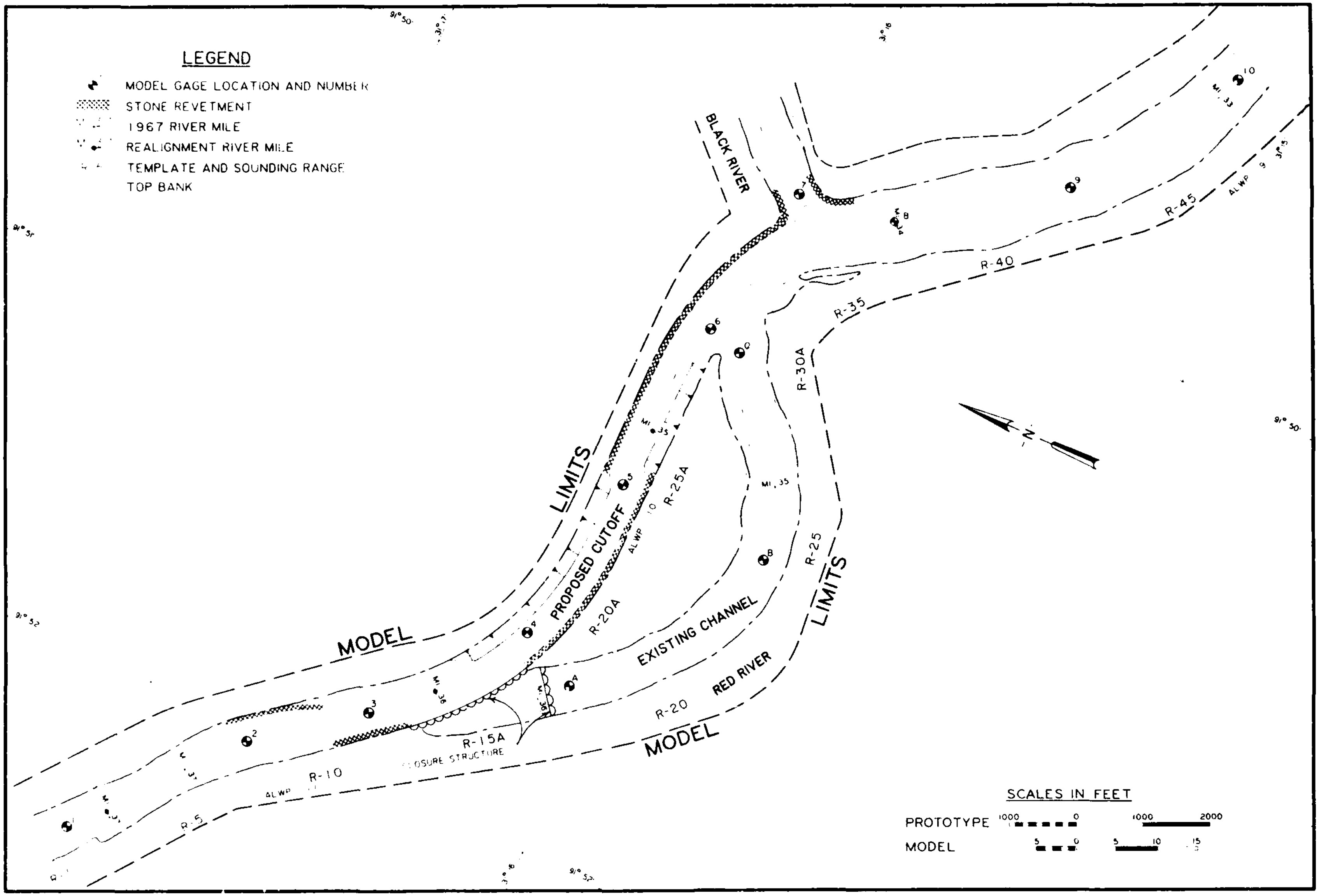


Figure 2. Model layout and gage location

surveying the model bed and to install structures in the model.

Model Adjustment

8. As the name implies, the bed and bars of movable-bed models are composed of material capable of being transported as bed load. Bank lines are normally fixed unless caving banks are expected to have a major impact on the study. Models capable of reproducing only bed-load movement are adequate to study shoaling and deposition problems, since suspended sediments do not normally play a significant role in scour and deposition in sand-bed streams where significant bed-load movement is occurring. Fixed bank lines and a coal bed were used in this study. Before a movable-bed model is used to test the effectiveness of proposed improvement plans, its ability to reproduce conditions similar to those that can be expected in the prototype must be demonstrated. Complete agreement between the model and the prototype cannot be obtained because of the inherent distortions incorporated in the model design and in the operation of the model. Because of these dissimilarities, the degree of reliability of this type of model cannot be fully established by mathematical analysis and must be based on model verification. Verification of the model involves the adjustment of various hydraulic forces, time scale, rate of introducing bed material, and model operating techniques. These adjustments are made until the model reproduces with acceptable accuracy the changes known to have occurred in the prototype during a given period. Various scale relationships and model operating procedures established during model verification are used in tests of various improvement plans. The degree of similarity between model and prototype data obtained during model verification is considered in the analysis of model test data.

Conventional procedure

9. To accomplish a normal verification, it is necessary to have two, preferably recent, prototype surveys of the channel in the test reach. The surveys should be about one year apart and should show the stages and discharge that occurred in the test reach between the two surveys. The model bed is initially molded to the earlier survey. The flows that occurred during the period between the surveys are introduced at the upper end of the model and the water surface at the downstream end of the model is controlled. This is done so that the stages in the center of the model agree with the stages that

occurred in the prototype during this period. Bed material is introduced at the upstream end of the model to simulate the bed material moving into the test reach. The quantity of bed material varies directly with the amount of flow. At the end of the period, the model bed is surveyed and the bed configurations are compared with those of the prototype survey for the end of the period. If the model does not reproduce the prototype survey closely enough, modifications are made to change the hydraulic forces, the time scale, the rate of introducing bed material, and the model operating techniques until the model satisfactorily reproduces the prototype bed configurations. Once the model has been verified, these scales and procedures are used in the testing program.

Procedure used

10. Since only one recent prototype survey of the test reach, March 1968 (Plate 1), was available, a conventional verification of the model was not possible. However, for this model to be of value, it was essential that it be adjusted to reproduce channel configurations generally representative of those expected in this reach of the Red River under similar circumstances. Accordingly, the adjustment of the model was initiated with the model bed molded to the prototype survey of March 1968. The flows that occurred in the prototype for the year preceding the survey, 13 March 1967-12 March 1968 (Plate 2), were introduced and the stage hydrograph in the center of the test reach was reproduced. The initial time scale, discharge scale, rate of introducing bed material, and model operating techniques were determined from past experience with similar models. The resulting bed configurations were compared with those of the prototype for March 1968. This procedure assumes no radical changes in channel alignment and that the hydrograph which shaped the bed should not significantly change the bed if it is repeated. Also implicit in this method of adjustment is the requirement that discharge scales are adjusted so that there is adequate bed-load transport. The amount of sediment introduced at the upstream model limit is adjusted so that the most upstream section of the model neither agrades nor degrades significantly. Progressive adjustments were made in the model scales and operating techniques following each adjustment hydrograph until a satisfactory adjustment was achieved.

Results

11. A comparison of the results of the final adjustment test (Plate 3) with those of the prototype survey of March 1968 (Plate 1) shows that the

model bed configurations generally reproduced the tendencies of the prototype. The channel upstream of the mouth of the Black River was somewhat deeper than the prototype but a review of the aerial photography showed considerable bank caving in this reach during the adjustment period. Material from the caving bank would be expected to increase bed load in the area and produce a shoaling condition rather than the deepening indicated by the model. Since most of this channel was to be eliminated by a cutoff, it was not deemed necessary to simulate bank caving in the area to achieve a more accurate reproduction of the bed configuration. The channel configuration downstream of the confluence of the Black River was satisfactorily reproduced. As a result of adjustment, the hydraulic scale relationship, time scale, and rate of introducing bed material were established. They were used in tests of the improvement plans.

PART III: TESTS AND RESULTS

Test Procedure

12. Tests were concerned with the development of a navigation channel 200 ft wide, 9 ft below the average low-water plane (ALWP) along a satisfactory alignment. Tests were conducted of two (Lorran Lake cutoffs) alignments (Plans A and B). Each alignment was tested with various dike systems and channel cross sections, and Plan B was tested with notches cut in the banks. Each plan and modification thereto was tested by reproducing the 1967-68 stage hydrograph, introducing crushed coal with each flow to simulate bed material moving into the test reach, and controlling the water surface at the downstream end of the model to a rating curve developed during model verification. Two modifications to Plan A were also tested with a low-water (1970-71) hydrograph (Plate 4), an average (1971-72) hydrograph (Plate 5), and a high-water (1972-73) hydrograph (Plate 6). The effect of upstream locks and dams on sediment transport was not considered; therefore, the rate of introducing bed material at the upper end of the model was the same as that required for model verification. Prior to the first test of each plan and of selected modifications, the bed of the existing channel was molded to the March 1968 prototype survey, and the cutoff channel was molded to a cross section and alignment furnished by the US Army Engineer District, New Orleans (LMN). Tests of the remaining modifications were initiated with the bed of the model to configurations that existed at the end of the previous test. Prior to some tests, a navigation channel was dredged in specific reaches, and the bed of the model was surveyed following each hydrograph. Navigation depth was considered to be el 0.0* through the test reach.

13. Most of the plan modifications were developed during preliminary tests. Promising modifications developed were incorporated in more comprehensive plans expected to [illegible]. Results of development tests were furnished to LMN but are not included in this report.

* All elevations (el) cited herein are in feet referred to National Geodetic Vertical Datum (NGVD) of 1929.

Plan A

Description

14. Plan A (Figure 3), the initial plan proposed by LMN, consisted of a 1.9-mile cutoff from mile 36.5 to 34.3 to increase the radius of the bend at the mouth of the Black River and the radius of the next bend upstream. The alignment of the cutoff, obtained from Plates 67-69 in the Portfolio of the Red River Waterway Design Memorandum No. 2, March 1974, contained two reverse 5,000-ft radius bends connected by a 2,500-ft-long tangent. The upstream bend was 4,500 ft long and connected to the existing channel with a 3,300-ft-long tangent at mile 36.5. The downstream bend joined the existing channel at mile 34.3. The cutoff channel was molded to the average cross section for a 4,500-ft radius curve (Figure 3) as obtained from Plate 5 of the above referenced portfolio. The channel upstream and downstream of the cutoff was molded to the prototype survey of March 1968 (Plate 1). Two longitudinal dikes (a 1,600-ft-long dike to el 11 at mile 36.4 on the left bank and a 1,300-ft-long dike to el 10 at mile 35.2 on the right bank) were installed to develop crossings in the cutoff. One closure dike was installed across the upstream entrance to the old bendway and another one was installed about 1/4 mile downstream in the bendway. These dikes were installed to top bank elevation to force all within-bank flows through the cutoff.

Results

15. Less than one-half the length of the channel above the Black River that was produced by Plan A (Plate 7) had sufficient depth for navigation, and it had a maximum width of [illegible] ft with much of the length 200 ft or less in width. The crossing at mile 36 was 9 ft above navigation depth, and the crossing at mile 34.9 was [illegible] ft above navigation depth.

Plan A-1

Description

16. [illegible]

dikes [illegible]

crossing; [illegible]

these [illegible]

[illegible]

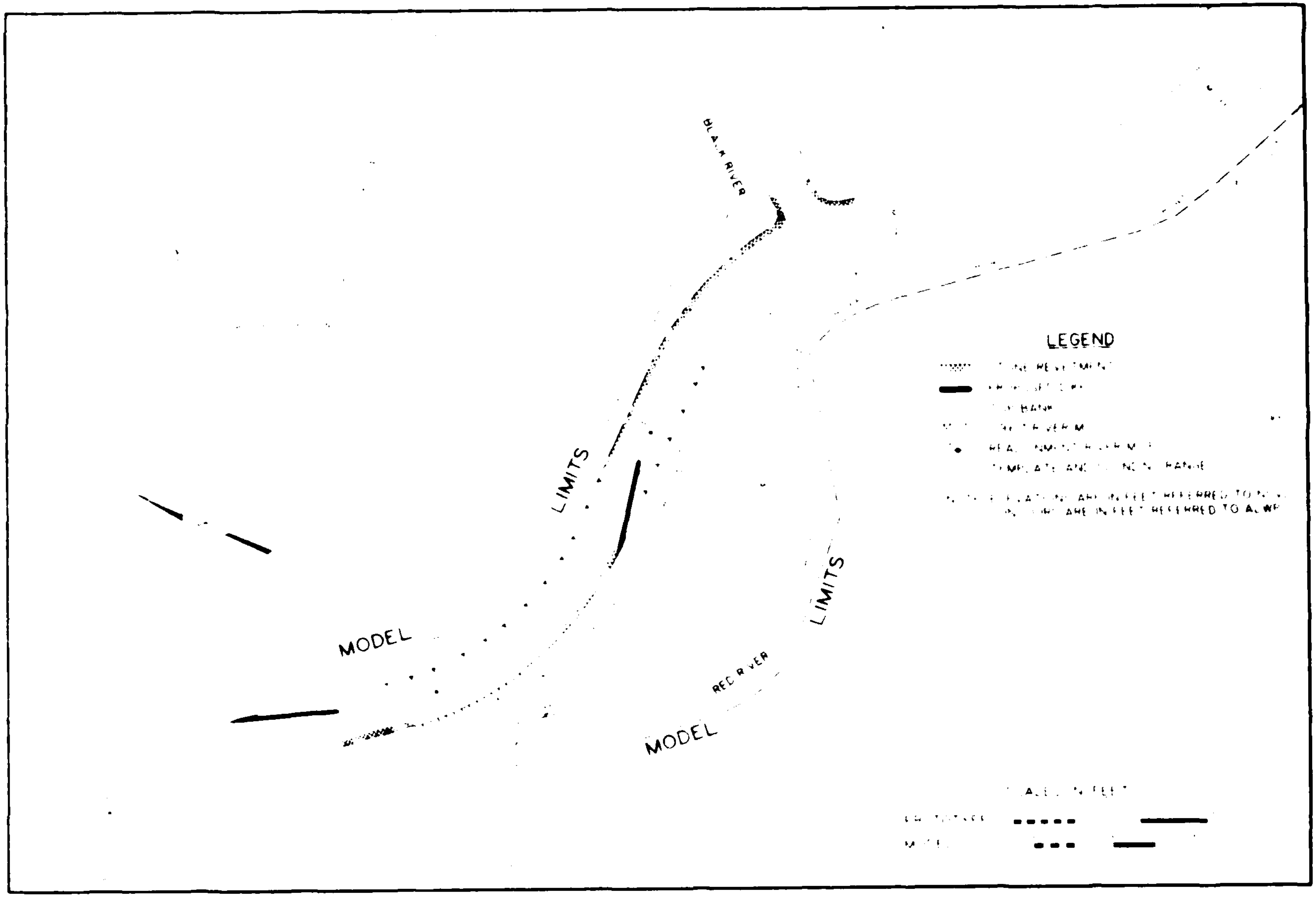


Figure 3. Plan A

to 34.44, an L-head dike at mile 34.9, and a longitudinal dike at mile 34.7) were installed in the cutoff to develop a deeper and wider channel. These dikes are listed in Table 1 and shown in Figure 4. The model of the channel bed was molded to the configurations that existed at the end of several development tests following testing of Plan A. These configurations are shown in Figure 4. The 1967-68 hydrograph was reproduced four times to determine if the channel would maintain its width and depth over a period of years.

Results

17. The results of the first hydrograph of Plan A-1 (Plate 8) indicated that this cutoff and system of dikes would produce a continuous navigation channel through the test reach. The navigation channel would have a minimum width of 175 ft and 89 percent of this channel above the Black River would be at least 200 ft wide. Downstream of the Black River about 1,400 ft of the channel would be less than 200 ft wide at navigation depth. This section would have a minimum width of 140 ft. Results of additional testing indicate that after four hydrographs the navigation channel would remain continuous through the test reach (Plate 9), but about 36 percent of the navigation channel upstream of the Black River would be less than 200 ft wide and have a minimum width of 150 ft. The minimum width of the channel downstream of the Black River increased to 300 ft, but a bar developed on the left bank just downstream of the Black River that shortened the length of the crossing. This bar could make it difficult for upbound tows to cross to the left bank and align with the entrance to the cutoff especially with significant flow out of the Black River.

Plans A-2 and A-3

Description

18. The dikes for Plan A-[illegible] were the same as those of Plan A-1 except for the modifications listed below. These modifications are shown in Figure [illegible] and listed in Table [illegible].

a. In the existing channel upstream [illegible], three spur dikes were installed [illegible] and [illegible], and two [illegible]

b. At the entrance [illegible] dike on the left bank at mile [illegible]

c. In the cutoff [illegible]

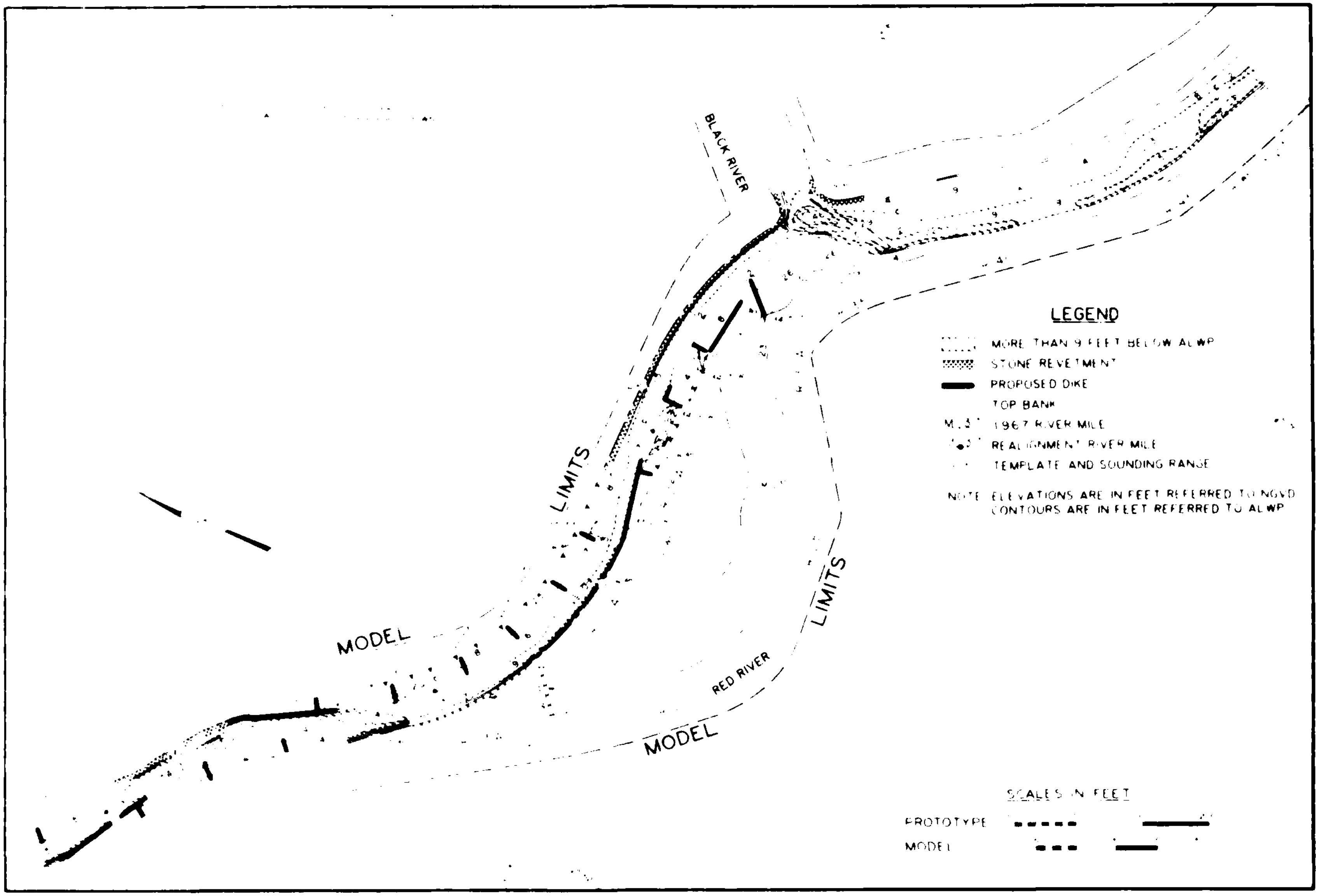


Figure 4. Plan A-1

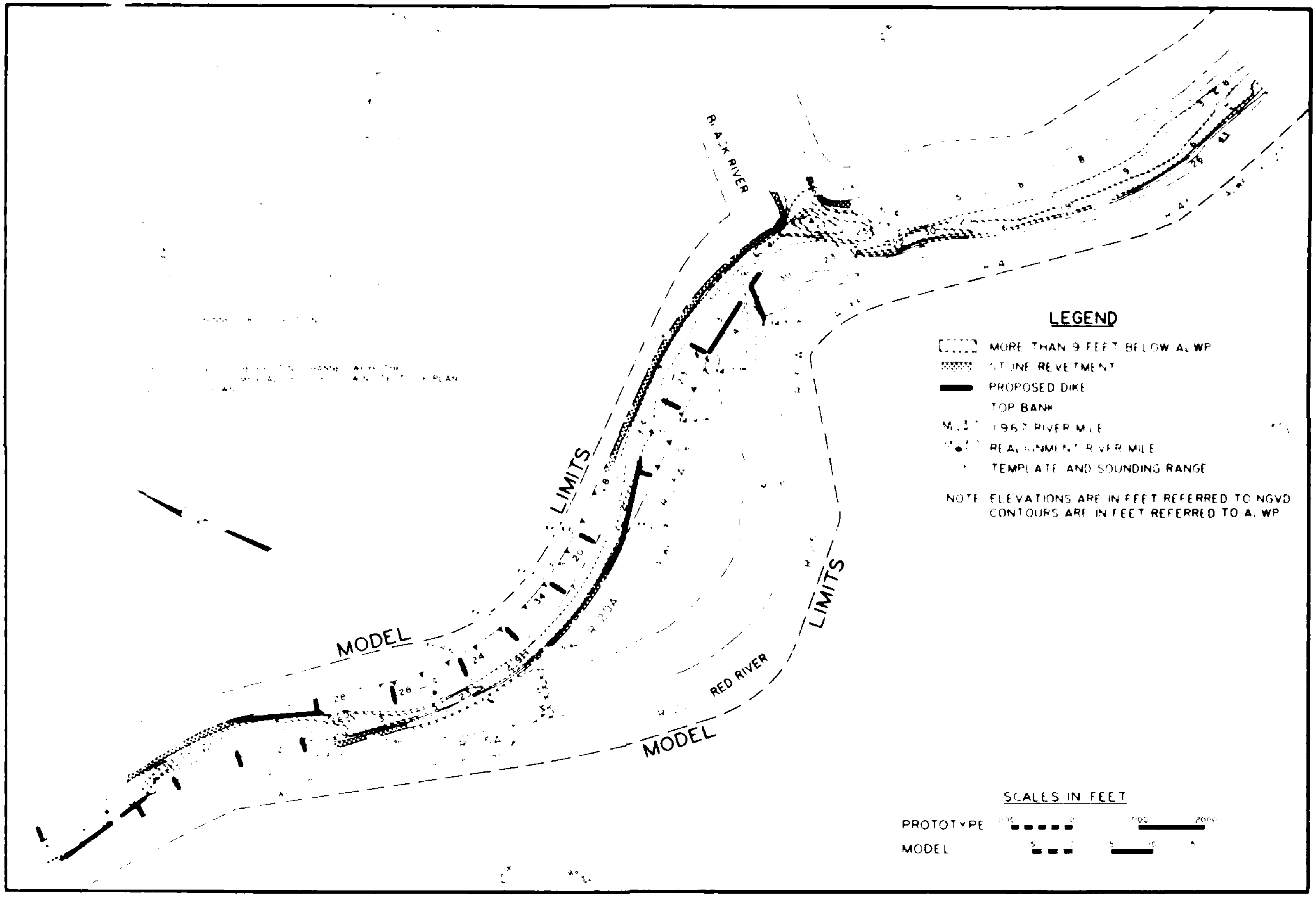


Figure 5. Plan A-2

miles 36.1, 35.89, 35.70, 35.50, and 35.33, and one on the right bank at mile 34.7 were lowered. The L-head of the dike on the right bank at mile 34.9 was removed and the remaining spur dike was lowered.

d. In the downstream entrance to the old bendway, the longitudinal dike at mile 34.7 was raised, the spur dike at mile 34.50 was shortened 90 ft, and a 150-ft-long wing was added.

The size of the cutoff channel was reduced considerably by filling with coal-bed material up to el 42 on the inside banks of the two curves. This resulted in a cross section almost equal to an average of those shown in the 1968 prototype survey for this reach. This cross section (Figure 5) was 30 ft less in width at el 0.0, 140 ft less at el 10, and 190 ft less at el 20 than the cross section for the cutoff for Plan A. The existing channel was molded to configurations that existed at the end of several preliminary tests following testing of Plan A-1. These configurations are shown in Figure 5.

19. For Plan A-3, a spur dike was installed to el 25 on the right bank at mile 36.67. The initial bed configurations for Plan A-3 were those that existed at the end of testing of Plan A-2. The dikes and beginning bed configurations for Plan A3 are shown in Figure 6.

Results

20. The navigation channel resulting from testing of Plan A-2 was continuous through the test reach along a satisfactory alignment, but only 54 percent of the navigation channel above the Black River was at least 200 ft wide. The minimum width of the navigation channel was 160 ft. Installing the dike at mile 36.65 for Plan A-3 increased the width of the navigation channel at this point but the channel in the cutoff deteriorated considerably. Some 44 percent of the navigation channel above the Black River was less than 200 ft wide. The minimum width of the navigation channel was 100 ft (Plate 10).

Plans A-4 and A-5

Description

21. Plan A-4 (Figure [illegible]) [illegible] vane, L-head, and longitudinal dikes as obtained [illegible] the [illegible] of the Red River Waterway Design Memorandum [illegible], March [illegible]. Fourteen vane dikes (miles 37.14, 36.9[illegible], 36.60, 36.4[illegible], [illegible], [illegible], [illegible], [illegible], 35.36, 35.20,

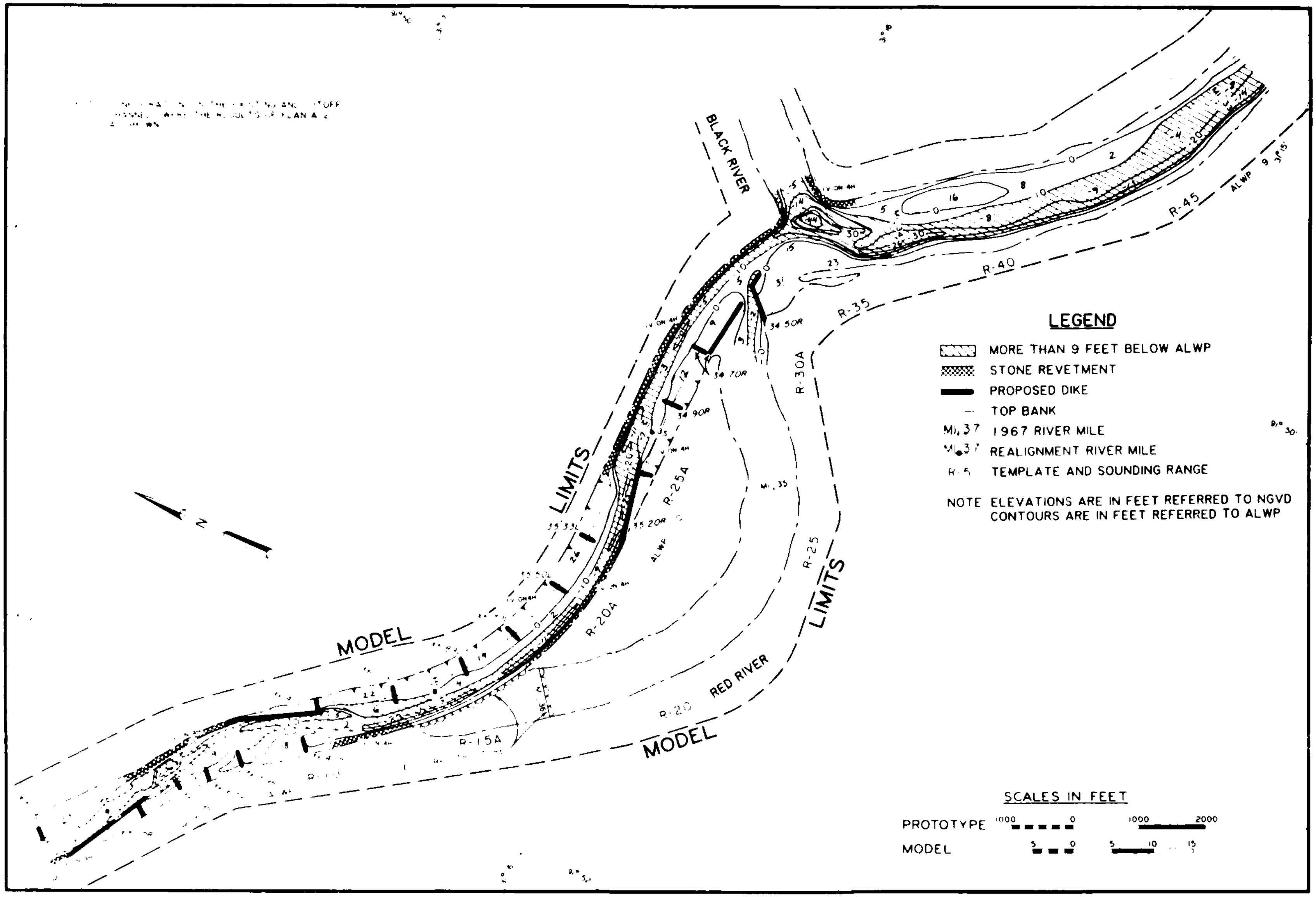


Figure 6. Plan A-3

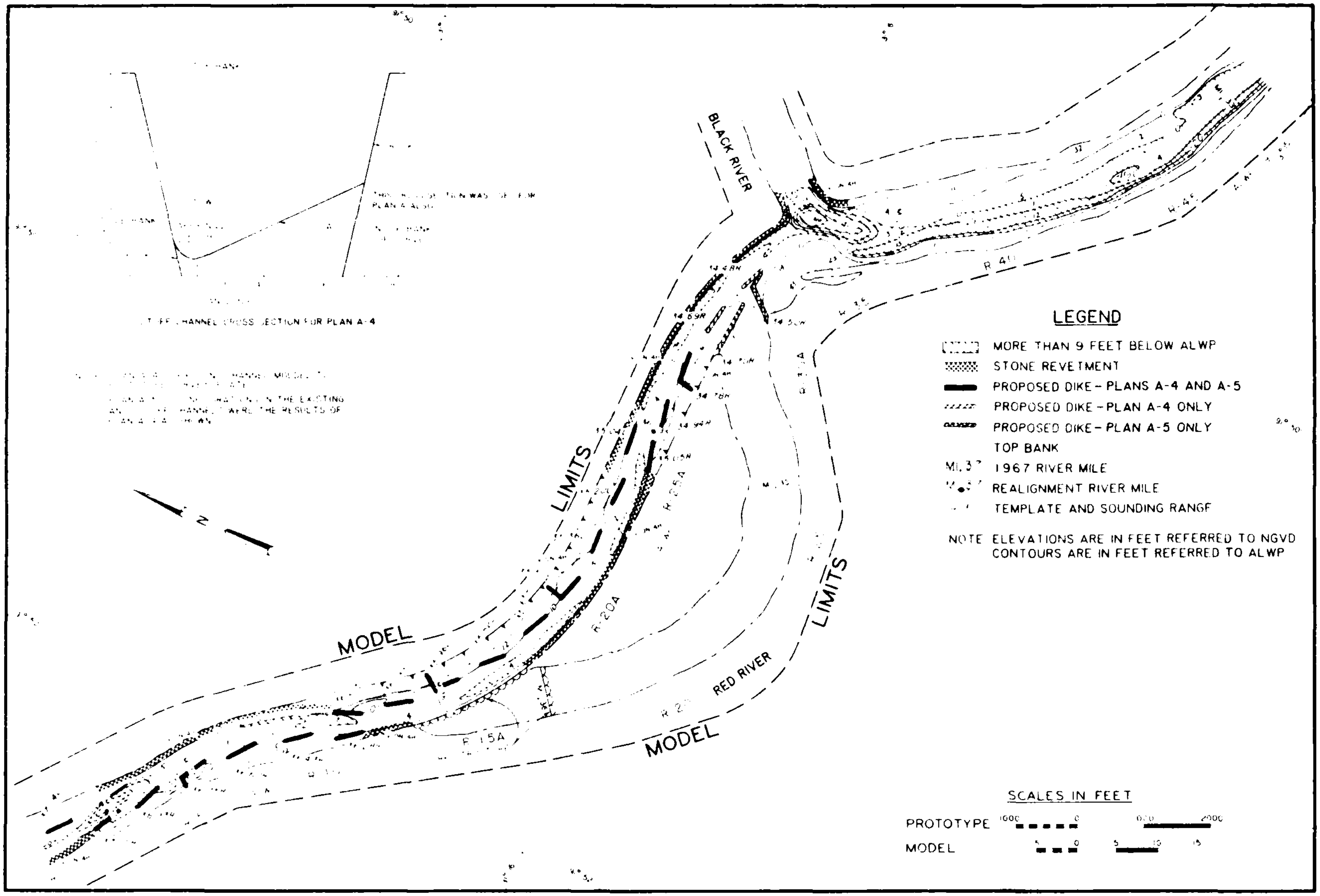


Figure 7. Plans A-4 and A-5

35.04, 34.94, 34.69, and 34.48), four L-head dikes (miles 36.75, 35.96, 35.51, and 34.78), and three longitudinal dikes (miles 37.04, 36.27, and 35.05) were installed as listed in Table 1. The cutoff channel was molded to the average cross section for a 4,000-ft radius curve as it was for Plan A. The existing channel upstream and downstream of the cutoff was molded to the prototype survey of March 1968. For Plan A-5 the vane dikes at the downstream entrance to the old bendway (miles 34.69 and 34.48) were removed and a longitudinal dike was installed to el 30 upstream of the entrance (mile 34.70) and an L-head dike was installed to el 40 downstream of the entrance (mile 34.50). The other dikes installed for Plan A-4 were raised to el 25. The dikes for Plan A-5 are listed in Table 1 and shown in Figure 7. The bed of the existing and cutoff channels were to configurations that existed at the end of testing of Plan A-4 as shown in Figure 7. The 1967-68 hydrograph was reproduced twice, the low-water hydrograph (Plate 4) was reproduced once, and the average hydrograph (Plate 5) was reproduced once.

Results

22. The results of testing of Plan A-4 indicated that this system of dikes would not maintain a continuous navigation channel in the test reach. About 33 percent of the channel above the Black River did not have navigation depth and only one third of this length had a channel more than 100 ft wide at navigation depth. Just downstream of the Black River a bar developed off the left bank that would hinder upbound navigation crossing to the left bank to align with the cutoff channel.

23. Results of tests of Plan A-5 (Plate 11) with two repetitions of the 1967-68 hydrograph indicate that this system of vane dikes raised to el 25 would develop a continuous navigation channel in about 91 percent of the reach above the Black River, and in the remaining 9 percent of the channel, the controlling depth would be only 1.0 ft above navigation depth. However, as with Plan A-4, approximately one third of this navigation channel had a width of more than 100 ft. The dikes installed in the downstream entrance to the old bendway developed a channel about 30 ft wide into the bendway at navigation depth. The bar on the left bank downstream of the Black River remained a hindrance to navigation.

24. Bed configurations resulting from testing of Plan A-5 with the low hydrograph (Plate 12) indicate that, with the lower discharges, the navigation channel in the upstream portion of the cutoff would increase slightly in width

but still only 52 percent of the navigation channel above the Black River would have at least a 100-ft width. At mile 34.9, the channel would shoal to a minimum of 1.0 ft above navigation depth. The bar on the left bank downstream of the Black River remained about the same as with the 1967-68 hydrograph.

25. Bed configurations resulting from testing of Plan A-5 with the average hydrograph (Plate 13), which has higher discharges than those of the 1967-68 hydrograph, indicate that with the higher discharges the navigation channel would be continuous downstream to mile 34.0 where a shoal with a maximum elevation 1.0 ft above navigation depth would extend across the channel. Only 48 percent of the navigation channel above the mouth of the Black River had a width over 100 ft and the minimum width was 25 ft.

Plans A-6 and A-7

Description

26. A system of dikes similar to those constructed on the Arkansas River near Adamsburg Landing were installed for Plan A-6 (Figure 8). Fifteen L-head dikes were installed from miles 36.9 to 34.3 at intervals of about 800 ft to develop the navigation channel upstream of the Black River. The angle between the spur portion and the L-head was 110 deg. The L-heads were all to el 28 but the spur portions in each group of three were stepped down. From upstream to downstream the elevations in each group were 28, 24, and 20. In addition to these L-head dikes, a vane dike (mile 37.19 on the left bank) and three longitudinal dikes (miles 37.0 and 35.2 on the right bank and mile 36.4 on the left bank) were installed to develop crossings at the desired locations. Also, a longitudinal dike at mile 34.7 and an L-head dike at mile 34.5 were installed on the right bank in the downstream entrance to the old bendway to develop an access channel into the bendway for recreation. These dikes are listed in Table 1 and shown in Figure 8. The cutoff channel was molded to the average cross section for a 4,500-ft-radius curve (Figure 8) as it was for Plans A and A-4. The existing channel was molded to configurations that existed at the end of testing of Plan A-5 (Plate 13). The 1967-68 hydrograph was reproduced twice to provide sufficient time for this plan to fully develop a channel. For Plan A-7 the dikes remained the same as for Plan A-6, but the cutoff channel was molded to the cross section at mile 35.06 in the

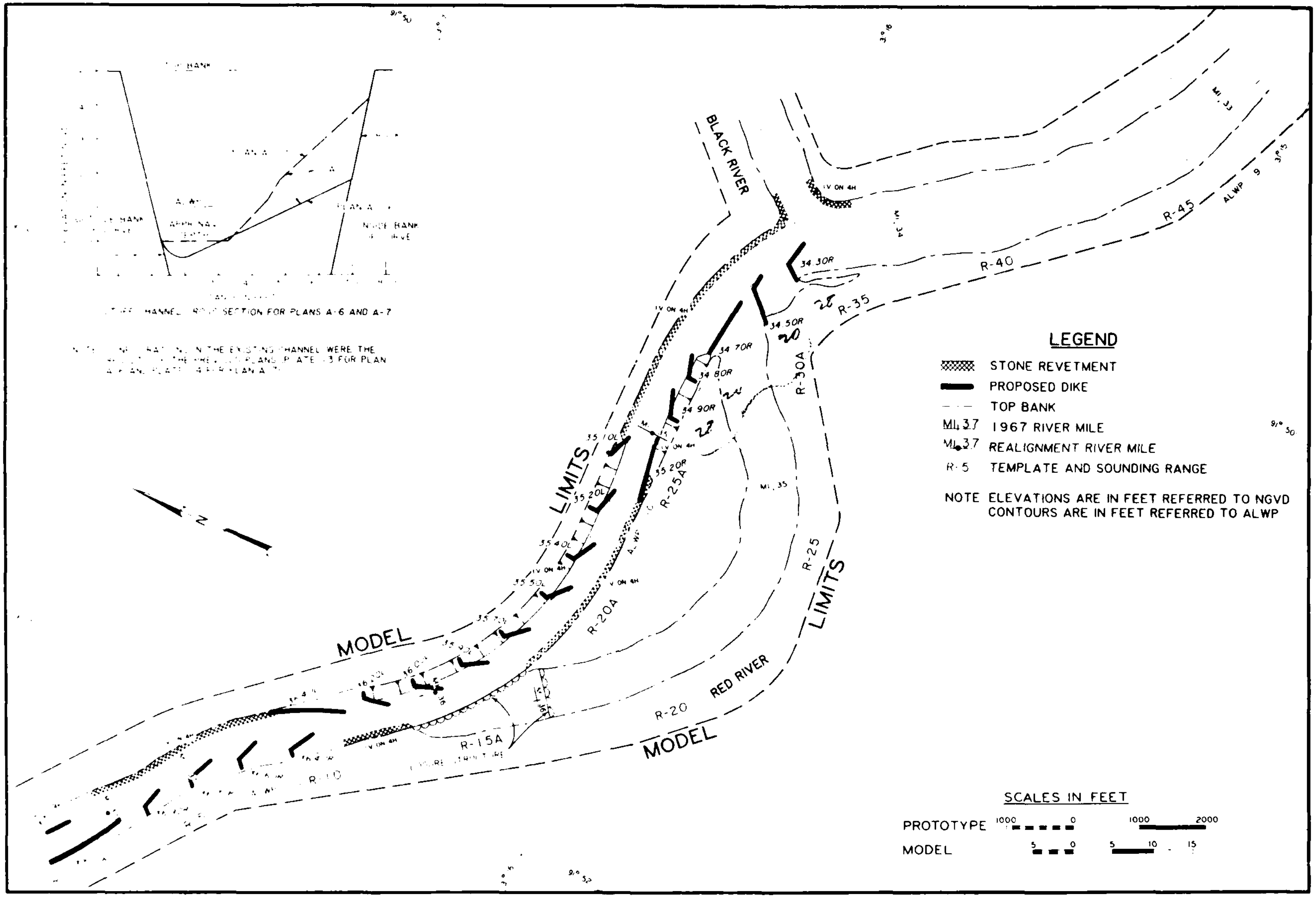


Figure 8. Plans A-6 and A-7

March 1968 prototype survey. The cross section shown in Figure 8 is about the same as the one used for Plan A-2 but is much smaller than the one used for Plan A. The existing channel was unchanged from that which existed at the end of testing of Plan A-6 (Plate 14).

Results

27. The navigation channel developed during the first hydrograph with Plan A-6 was continuous through the test reach but only about 20 percent of the navigation channel above the Black River was at least 200 ft wide. The minimum width of the navigation channel was 60 ft (mile 34.95). However, with the second hydrograph (Plate 14), a shoal developed across the navigation channel at mile 34.9 that had a maximum elevation 3 ft above navigation depth. Only 22 percent of the navigation channel above the Black River was at least 200 ft wide. The channel downstream of the Black River was over 200 ft wide at navigation depth except for a bar 1 ft above navigation depth on the left bank at mile 34.1, and the channel alignment was satisfactory.

28. With Plan A-7, excessive scouring occurred along the inside of bends of banks in the cutoff and considerable deposition occurred in the cutoff channel (Plate 15). Approximately 19 percent of the navigation channel above the Black River was at least 200 ft wide and just 55 percent had a width of at least 100 ft. A bar developed above navigation depth across the channel at mile 36.9.

Plans A-8 and A-9

Description

29. For Plan A-8 (Figure 9) all of the dikes in the model were removed, five dikes (three in the existing channel upstream of the cutoff and two in the downstream entrance to the old bendway) were installed as shown in Figure 9, and the cutoff was molded to the cross section at mile 36.41 in the March 1968 prototype survey. The dikes are listed in Table 1. A 1,000-ft-long longitudinal dike with a 200-ft-long dike connecting its downstream end to the bank was installed to el 50 on the right bank at mile 37.10. Two L-head dikes with 140-ft-long root sections and 400-ft-long L sections were installed on the right bank to el 35 at miles 36.9 and 36.7. These dikes were designed to develop the desired flow pattern upstream of the cutoff. A 300-ft-long longitudinal dike to el 30 and an L-head dike with a 600-ft-long root

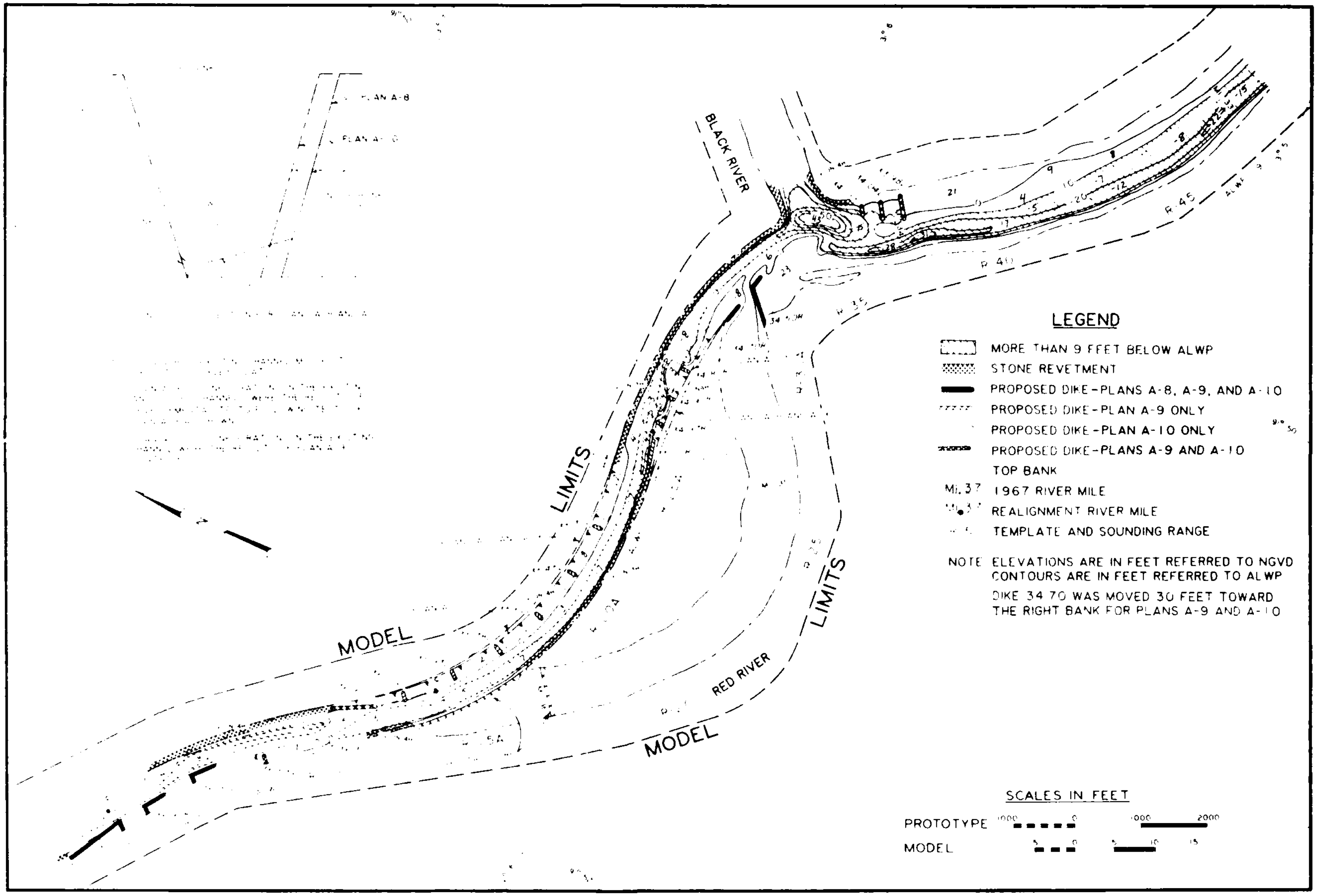


Figure 9. Plans A-8, A-9, and A-10

section and a 200-ft-long L section to el 40 were installed on the left bank at miles 34.7 and 34.5, respectively, to maintain an access channel into the old bendway for recreation. The cross section for the cutoff channel for this plan was 120 ft wider at el 0.0 but from 1[illegible] to 112 ft narrower from el 10 to 50 than the one for Plan A. Both banks for Plan A-8 were molded in rock to prevent bank scour. The existing channel upstream and downstream of the cut-off was molded to the prototype survey of March 196[illegible] (Plate [illegible]).

30. Plan A-9 was the same as Plan A-8 except for the following dike modifications which are listed in Table 1 and shown in Figure 9:

a. In the existing channel upstream of the cutoff, a 100-ft-long spur dike to el 25 was installed on the right bank at mile 36.53.

b. In the upstream curve in the cutoff, a [illegible]50-ft-long longitudinal dike on the left bank at mile 36.30 to el 25 and six 100-ft-long spur dikes were installed on the left bank to el 25 at miles 36.10, 35.93, 35.78, [illegible], [illegible], and 35.[illegible], respectively.

c. In the downstream curve of the cutoff, a [illegible]00-ft-long longitudinal dike to el 35 and three [illegible],[illegible]00-ft-long spur dikes to el 25 were installed on the right bank at miles [illegible], [illegible], 34.90, and 34.80, respectively.

d. In the downstream entrance to the old bendway, the longitudinal dike on the right bank at mile [illegible] was moved 30 ft toward the right bank.

e. On the left bank downstream of the Black River, a 150-ft-long spur dike to el 23, a 150-ft-long spur dike to el 20, and a 400-ft-long spur dike to el 17 were installed at miles 34.10, 34.04, and 33.98, respectively.

The channel bed was molded to configurations that existed at the end of several development tests following testing of Plan A-8. Those bed configurations are shown in Figure 9.

Results

31. The bed configurations resulting from [illegible] Plan A-9 indicate that this plan would maintain a [illegible] depth through the test reach, but this channel would be [illegible] approximately [illegible] ft at mile 36.1, 100 ft at mile [illegible] at other points. Only about [illegible] percent [illegible] Black River was over 200 ft wide, [illegible] would make it difficult for upbound navigation [illegible] the entrance of the cutoff channel. [illegible]

Plan A-9 (Plate 16) indicated that the channel had deteriorated. A shoal developed to a height of 3 ft above navigation depth at mile 36.3, and only 50 percent of the navigation channel above the Black River had a width of at least 200 ft. The dikes installed downstream of the Black River scoured the bar on the left side of the channel to below navigation depth. This would allow upbound navigation to start crossing to the left bank as far downstream as mile 33.6.

Plan A-10

Description

32. For Plan A-10, nine 100-ft-long spur dikes and one 300-ft-long longitudinal dike between miles 36.10 and 34.8 were removed and a 100-ft-long spur dike was installed on the right bank to el 20 at mile 36.32. The channel end of the dike at mile 36.32 was 280 ft from the left bank at el 0.0. The inside banks of the cutoff channel were moved riverward 30 ft. The bottom of the cutoff channel was molded to the cross section at mile 36.[illegible] in the March 1968 prototype survey as it was for Plan A-8. The existing channel was molded to configurations that existed at the end of testing of Plan A-9 (Plate 16). The dikes and cross section for this plan are shown in Figure 9 and the dikes are listed in Table 1.

Results

33. The navigation channel resulting from testing of Plan A-10 (Plate [illegible]) was continuous through the reach but only 6[illegible] percent of the channel above the Black River was at least 200 ft wide. Several places in the cutoff channel were only [illegible] ft wide at navigation depth.

Plan A-11 and A-[illegible]

Description

[illegible] for Plan A-11 were the same as those for Plan A-10, except [illegible] on the right bank at mile 36.[illegible] [illegible] installed [illegible] el 20 [illegible] the right [illegible]. The [illegible] dike was [illegible] ft from the left bank [illegible]. The [illegible] banks of the cutoff channel were moved riverward [illegible] the channel bed was [illegible]. The existing channel bed was unchanged from configurations [illegible]

that existed at the [illegible] testing [illegible] date [illegible]. The dikes and channel [illegible] are shown in Figure [illegible] and the dikes are listed in Table [illegible].

[illegible] Plan A-[illegible] (Figure [illegible]) was the same as Plan A-[illegible] except three spur dikes and [illegible] extension [illegible] existing spur dike were installed. A 150-ft-long spur dike [illegible] was installed [illegible] the left bank at mile [illegible], a [illegible]-ft-long spur dike [illegible] was installed on the right bank at mile 36.[illegible]9, a [illegible]-ft-long spur dike [illegible] was installed [illegible] the right bank at mile 34.69, and a [illegible] extension [illegible] was added to the spur dike on the right bank at mile [illegible].56. The channel bed [illegible] were those that existed at the [illegible] Plan A-[illegible]. The [illegible] hydrograph was reproduced once, the average [illegible] was reproduced once, and the high-water hydrograph (Plate [illegible]) was reproduced once.

Results

[illegible]. Results [illegible] resulting from tests [illegible] indicated that [illegible] would develop [illegible] through the test reach, but [illegible] the navigation channel [illegible] ft wide at the [illegible] ft wide [illegible] the [illegible] ft wide in the downstream end. [illegible] percent of the navigation [illegible] downstream of the Black River was at least [illegible] ft wide.

[illegible] with the [illegible] the test reach with a minimum width [illegible] ft. [illegible] the Black River [illegible] shown [illegible] indicate that [illegible] would maintain the [illegible] with about [illegible] percent of the channel [illegible] the Black River [illegible] ft wide. The minimum width [illegible]. The [illegible] flow [illegible] the high-water hydrograph would [illegible] upstream of the [illegible]

[illegible]

[illegible]. The [illegible] channel [illegible]

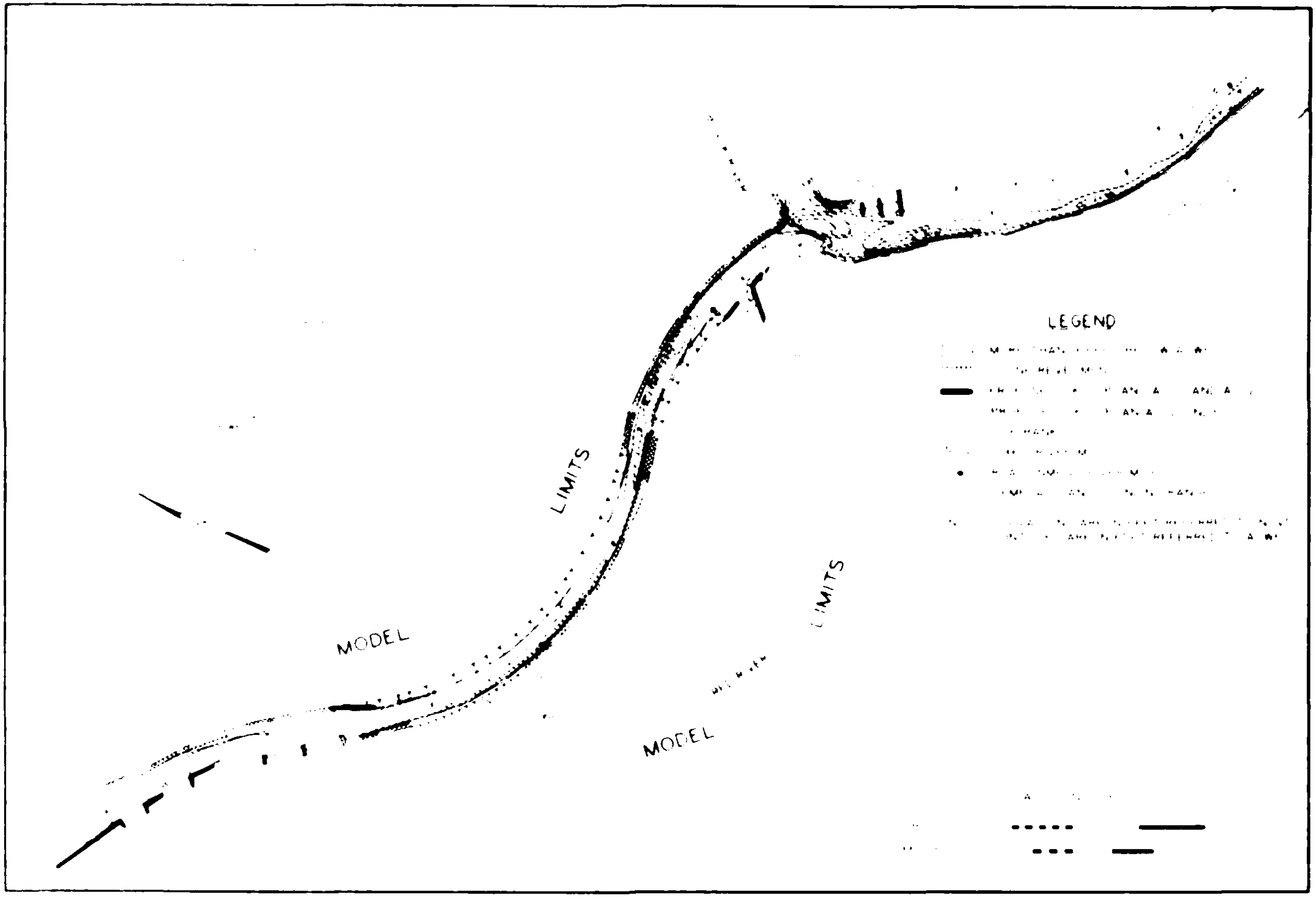


Figure 10. Plans A-11 and A-12

[illegible] level
[illegible]
[illegible] depth
[illegible]

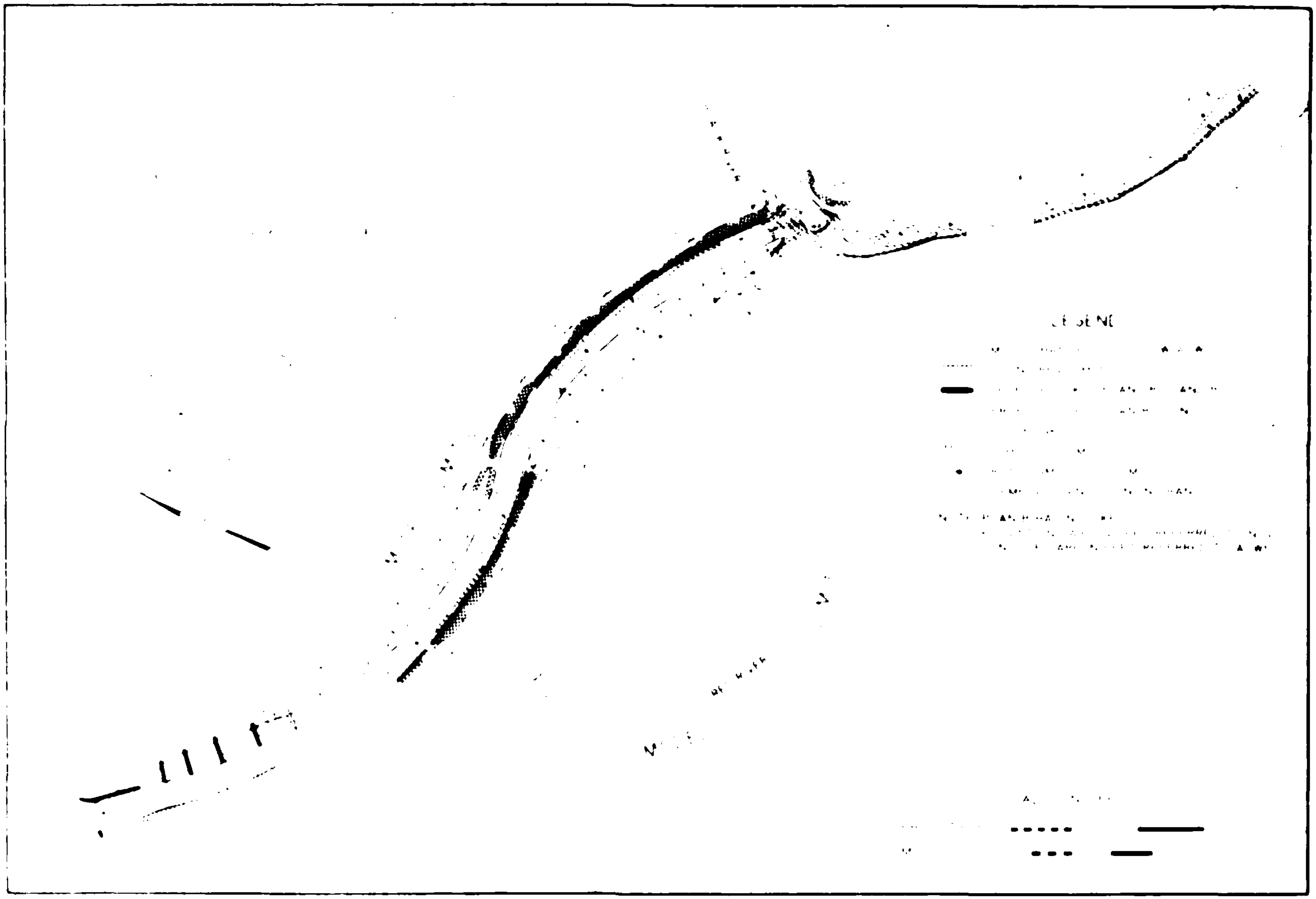


Figure 11. Plans B, B-1, and B-2

to the average cross section for an 8,000-ft-radius curve (Figure 11) as obtained from Plate 5 of the Red River Waterway Portfolio of Design Memorandum No. 2, March 1974. The existing channel was molded to the prototype survey of March 1968. A 200-ft-wide navigation channel was dredged to el 0.0 in the existing channel upstream of the cutoff. The 1967-68 hydrograph was reproduced twice.

Results

41. The bed configurations existing at the end of the second hydrograph with Plan B (Plate 21) indicate that with this plan only 31 percent of the channel above the Black River would have navigation depth and the maximum width of the navigation channel would be 150 ft. More than one half of this navigation channel would be less than 100 ft wide. The controlling elevation in the channel would be [illegible] ft above navigation depth. The results gave no in[illegible] different bed development for different bank slopes.

Plans B-1 and B-2

[illegible]

[illegible] Plan B-1 (Figure 11) was the same as Plan B except six dikes [illegible] were installed in the existing channel upstream of the cutoff. The [illegible] dikes was to develop a crossing to the right bank at the upstream entrance to the cutoff and the protected banks on the inside of the two curves in the cutoff were shifted riverward [illegible] 290 ft to limit the channel [illegible] ft at el 0.0. On the right bank, a 150-ft-long spur dike was [illegible] at mile [illegible].0. On the left bank, a 950-ft-long longitudinal dike was installed to el 45 at mile 37.0, and four spur dikes were installed [illegible] at miles 36.8, 36.[illegible], 36.6, and 36.[illegible]. The channel ends of the left [illegible] spur dikes were 300 ft from the right bank at el 0.0. The banks on the [illegible] the cutoff channel were molded in crushed stone to a [illegible] the cutoff channel was molded in coal to the [illegible] for an 8,000-ft-radius curve (Figure 10) as it was for [illegible] channel was that which existed at the end of testing of [illegible] was dredged to el 0.0 upstream [illegible] spur dike was in[illegible] left bank [illegible]. The channel end of this dike [illegible] the right bank at el [illegible]. The dikes are listed in Table 2 and

shown in Figure 11. The bed for both the existing and cutoff channels was that which existed at the end of testing of Plan B-1. The 1967-68 hydrograph was reproduced twice.

Results

43. The channel bed developed with Plan B-1 indicated that this plan would maintain a continuous navigation channel through the test reach except for 400 ft at mile 37 where the channel bed was 1 ft above navigation depth. Sixty-three percent of the navigation channel above the Black River was at least 200 ft wide with the remainder no less than 100 ft wide. The channel into the downstream end of the old bendway was below navigation depth. The bar on the left bank downstream of the Black River would hinder upstream navigation when crossing to the left bank to align with the entrance to the cutoff channel.

44. The resulting bed configurations for the second hydrograph with Plan B-2 (Plate 22) show that the shoal that had developed at mile 37 with Plan B-1 had been scoured to below navigation depth, thus providing a continuous navigation channel through the test reach. However, only 51 percent of the channel above the Black River was at least 200 ft wide. The channel into the downstream end of the old bendway was still below navigation depth, but the bar downstream of the Black River developed above navigation depth to within 200 ft of the right bank. This left a channel alignment that would hinder river traffic except during high water. Test results gave no indication of different bed development for different bank slopes.

Plans B-3, B-4, and B-5

Description

45. Plan B-3 (Figure 12) was the same as Plan B-2 except the downstream curve in the cutoff was pivoted so its downstream end was moved 340 ft toward the existing channel to improve the alignment with the existing channel downstream of the Black River. Above el 16.7, the slope of the inside and outside banks of this curve were changed to 1 on 4. The channel bed of this curve was molded in coal to the average cross section for an 8,000-ft-radius curve (Figure 12) as it was for Plans B and B-1. The rest of the channel bed was molded to configurations existing at the end of testing of Plan B-2 (Plate 22) except a 300-ft-wide channel was dredged to el 0.0 through the bar at mile 34.0. For

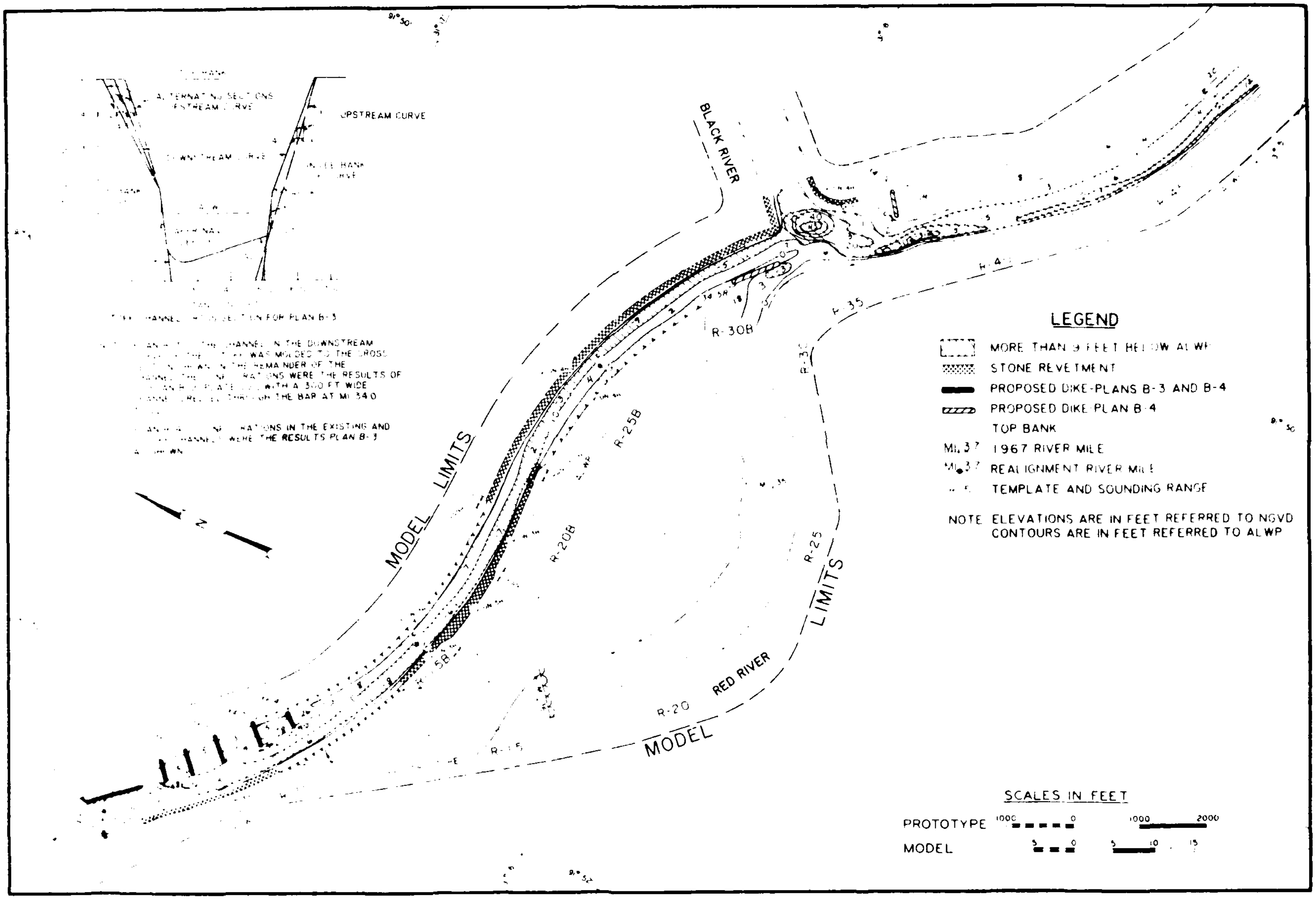


Figure 12. Plans B-3 and B-4

Plan B-4 (Figure 12), an 800-ft-long longitudinal dike was installed to el 35 on the right bank at the downstream entrance to the old bendway (mile 34.5) and a 400-ft-long spur dike was installed to el 20 on the left bank at mile 34.0. The channel bed was to configurations existing at the end of testing of Plan B-3. For Plan B-5 (Figure 13), the spur dike installed on the left bank at mile 34.0 for Plan B-4 was removed and an L-head dike was installed to el 20 at mile 34.1. The spur portion of this dike was 135 ft long and the L-head was 720 ft long at an angle of 110 deg with the spur portion. The channel bed was to configurations existing at the end of testing of Plan B-4. The dikes are listed in Table 2 and shown in Figure 13.

Results

46. The navigation channel with Plan B-3 was continuous through the test reach except for 800 ft at the upstream end of the model where a shoal to 3 ft above navigation depth developed across the channel. Thirty-eight percent of the navigation channel above the Black River was at least 200 ft wide, and the remainder had a width of no less than 175 ft. The channel downstream of the Black River had a width of over 200 ft but a bar developed on the left bank at mile 34.0 that would hinder upstream river traffic from crossing to the left bank to align with the cutoff channel. The bed configurations resulting from tests with Plans B-4 and B-5 were similar to those with Plan B-3, except that the L-head dike installed at mile 34.1 for Plan B-5 caused the bar on the left side of the channel to scour to below navigation depth (Plate 23). This would allow upbound tows to begin crossing to the left bank as far downstream as mile 33.7. The navigation channel for Plans B-4 and B-5, as for Plan B-3, was continuous through the test reach except for about 800 ft at the upstream end of the model. For Plan B-5 the minimum width of the navigation channel (except for the upper 800 ft) was reduced to 130 ft, and only 8 percent of the channel above the Black River was at least 200 ft wide at navigation depth.

Plan B-6

Description

47. Plan B-6 was the same as Plan B-5 except the outside bank of both curves in the cutoff was shifted riverward 50 ft and the slope of the outside bank of the upstream curve above el 16.7 was changed to 1 on 4. The bed of

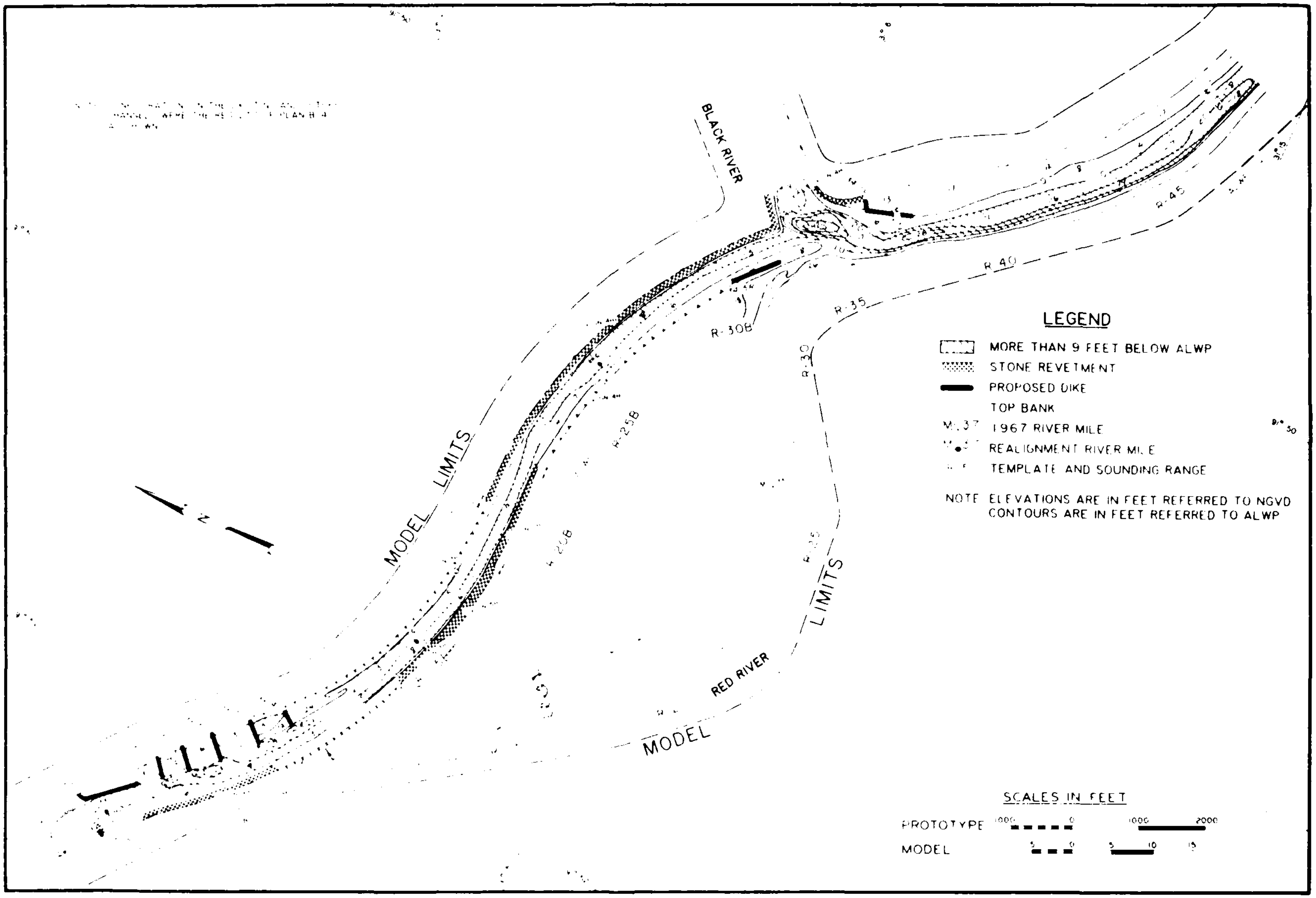


Figure 13. Plan B-5

the channel was molded in coal at el -10. This provided a cutoff channel with stabilized banks with widths of 250 ft at el 0.0 and 225 ft at el -10 for the downstream curve and 208 ft at el -10 for the upstream curve as shown in Figure 14. The existing channel was to configurations existing at the end of testing of Plan B-5 (Plate 23). The 1967-68 hydrograph was reproduced twice.

Results

48. The bed configurations resulting from testing of the first hydrograph with Plan B-6 showed a continuous navigation channel through the test reach except for 300 ft at the upstream end of the model. Seventy-six percent of the navigation channel upstream of the mouth of the Black River was at least 200 ft wide. Following testing of the second hydrograph, 66 percent of the navigation channel upstream of the Black River was at least 200 ft wide and the minimum width in the remainder of the channel was 175 ft. The navigation channel downstream of the Black River was over 200 ft wide along a satisfactory alignment. The access channel into the downstream entrance of the old bendway had a controlling elevation 4 ft above navigation depth.

Plan B-7

Description

49. Plan B-7 was the same as Plan B-6 except the left bank of the cutoff channel was shifted riverward 50 ft and the slope of the bank of the upstream curve was made the same as for the downstream curve. The bed of the channel was molded in coal to el -10. This provided a cutoff channel with stabilized banks and widths of 300 ft at el 0.0 and 275 ft at el -10, as shown in Figure 15. The existing channel was unchanged from bed configurations existing at the end of testing of Plan B-6 (Plate 24). The 1967-68 hydrograph was reproduced three times.

Results

50. The bed configurations resulting from testing of the first hydrograph for Plan B-7 showed that the coal being introduced into the upstream end of the model to simulate sediment moving into the reach had deposited in the channel only as far downstream as mile 35.5. Downstream of this point the channel was still 300 ft wide at el 0.0. Results of the second hydrograph showed that this sediment had moved downstream to mile 34.8. The bed configurations from testing of the third hydrograph (Plate 25) indicated that the

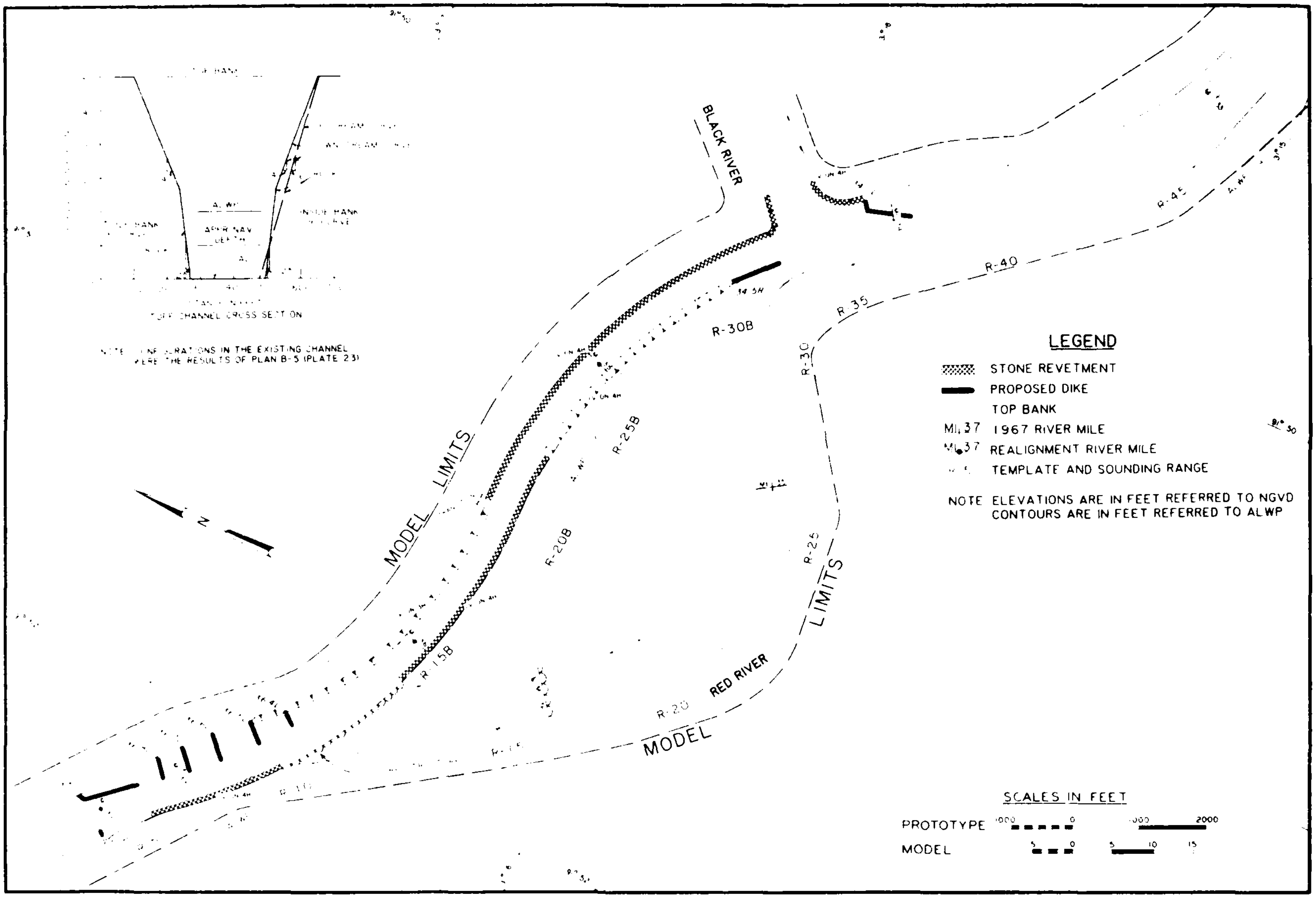


Figure 14. Plan B-6

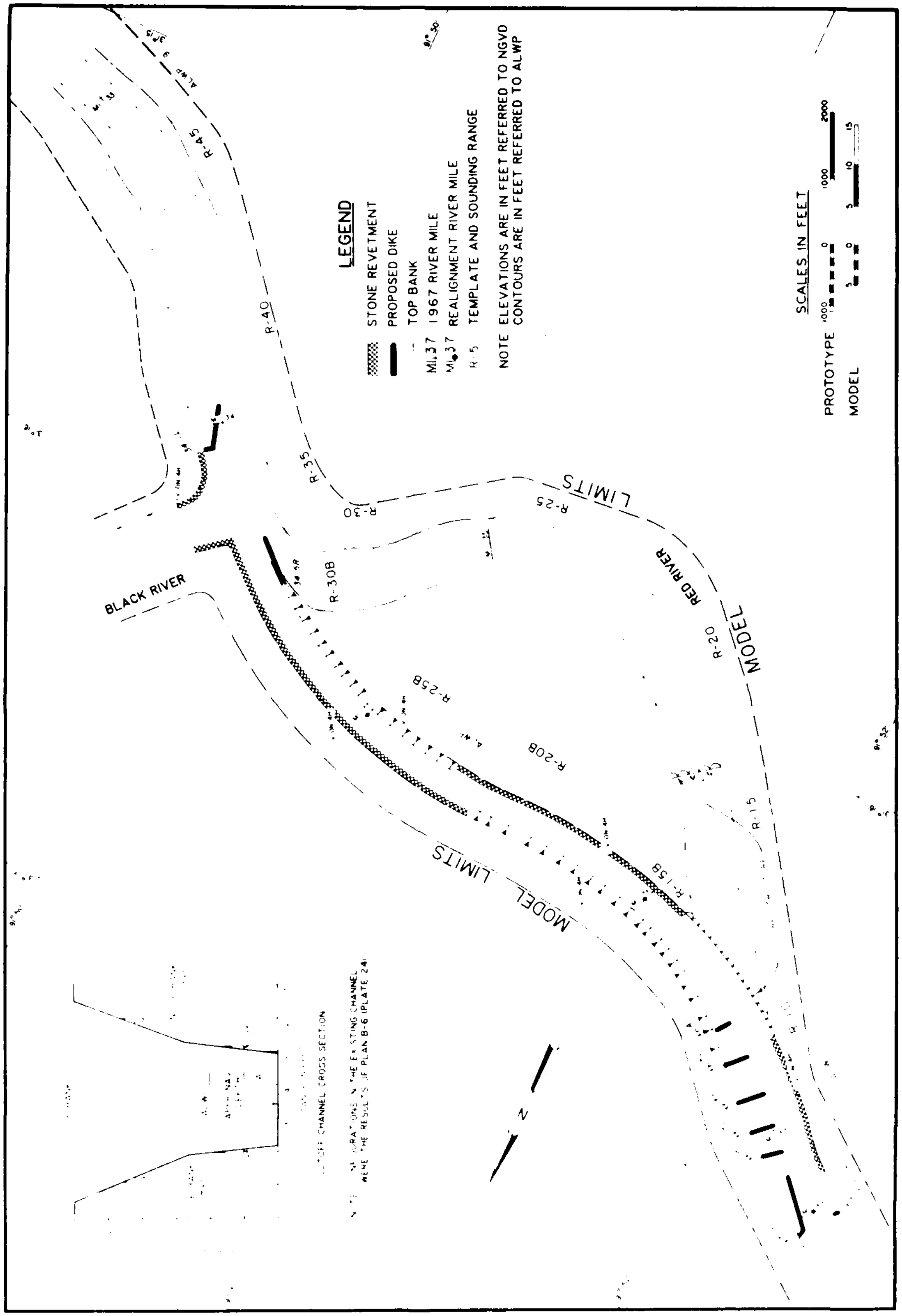


Figure 15. Plan B-7

sediment had moved through the model leaving a navigation channel through the test reach except for 1,000 ft at the upstream end of the model. Upstream of the Black River, 58 percent of the navigation channel had a width of 200 ft or more with a minimum width of 175 ft in the remainder of the reach. The channel below the Black River was over 200 ft wide at navigation depth and was along a satisfactory alignment. The access channel into the downstream entrance to the old bendway had a controlling elevation of 7 ft (3 ft below the ALWP).

Plan B-8

Description

51. Plan B-8 (Figure 16) was the same as Plan B-7 except three notches were cut in the outside banks of the two curves in the cutoff to determine if they would cause enough disturbance to the flow to affect the development of the bed configurations. These notches were 250 ft wide by 50 ft deep from the bottom of the channel to top bank. They were 1,000 ft apart (from center to center) with the first one in the upstream curve at mile 36.15 and the first one in the downstream curve at mile 35.10. The channel bed was molded to configurations existing at the end of testing of Plan B-7 (Plate 25). The 1967-68 hydrograph was reproduced twice.

Results

52. The navigation channel developed with Plan B-8 was continuous through the test reach except for 600 ft at the upstream end of the model where a bar developed across the channel to el 3. Fifty percent of the navigation channel above the Black River for the first hydrograph was over 200 ft wide with a minimum width of 150 ft in the remainder of the channel. With the second hydrograph, only 26 percent of the navigation channel above the Black River had a width of 200 ft (Plate 26), but the minimum width of the navigation channel remained 150 ft. A bar developed along the left side of the channel at mile 34.1 that would hinder upbound tows from crossing to the left bank to align with the cutoff channel, but this bar was only 1 ft above navigation depth and turbulence caused by passing tows could possibly keep it from developing. The results of Plan B-8 gave no indication that notches cut in the bank would help in the development of a wider or deeper channel.

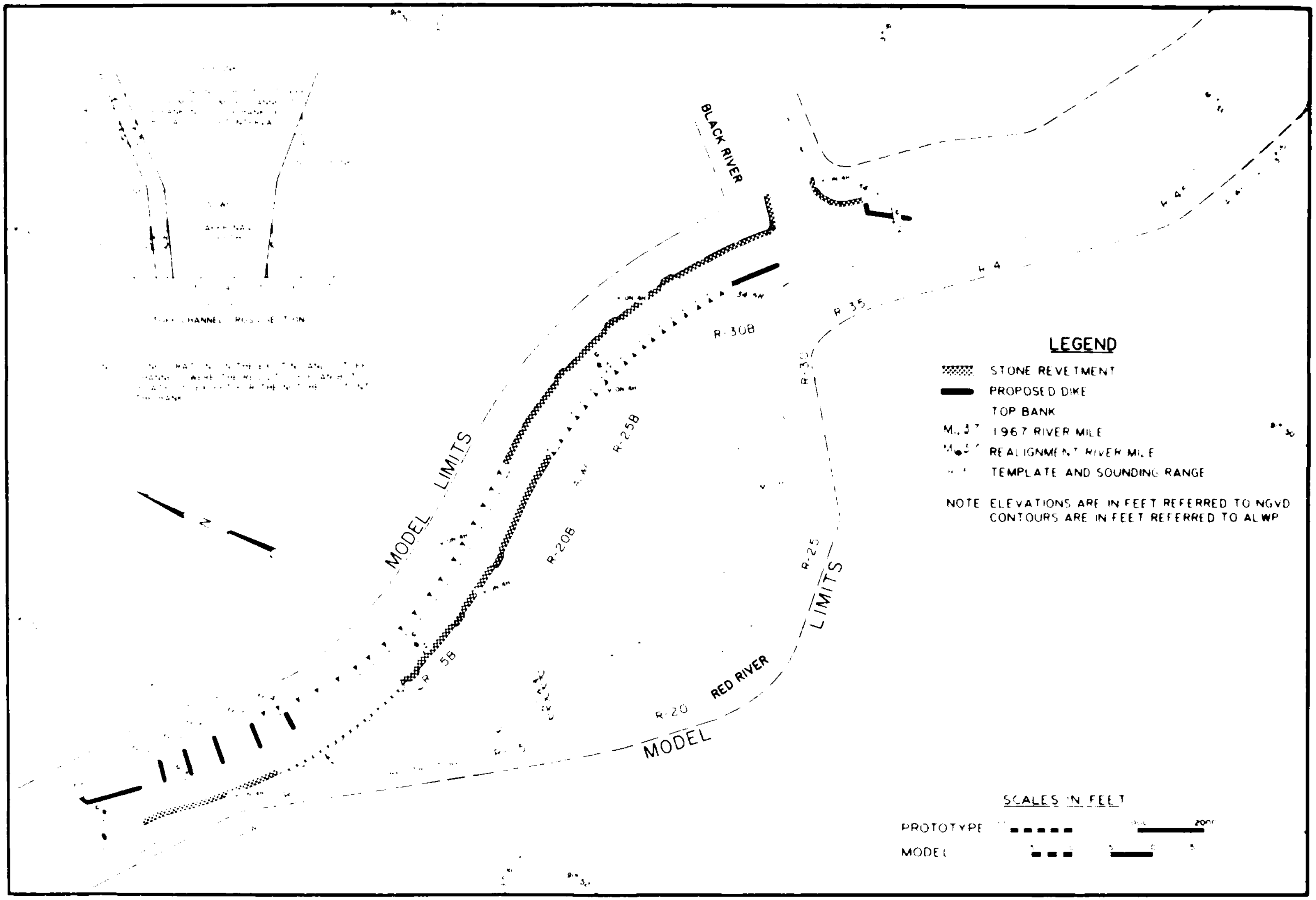


Figure 16. Plan B-8

Discussion of Results--Plan B

53. The cutoff channel for Plan B followed the alignment of two reverse curves with radii of over 7,000 ft. Eight of the nine plans tested developed a navigation channel through the test reach except for the first 1,000 ft of the model which was affected by model entrance conditions and was upstream of the dike systems. The most effective plan tested (Plan B-6) developed a navigation channel at least 200 ft wide through 76 percent of the reach above the Black River with the first hydrograph. Additional repetitions of the hydrograph reduced this to 66 percent with at least a width of 200 ft and a minimum width of 175 ft in the remainder of the channel. This plan contained a cutoff channel with stabilized banks at widths of 250 ft at el 0 and 225 ft at el -10, seven dikes upstream of the cutoff, one dike in the cutoff, and one dike downstream of the cutoff. Results indicate, as did those of Plan A, that the proposed overall channel would be too wide to maintain a navigation channel of adequate width and depth. Reducing the width of the overall channel and stabilizing the banks would be effective in increasing the width of the navigation channel.

PART IV: SUMMARY OF RESULTS AND CONCLUSIONS

Model Limitations

54. The limitations of the model based on model verification, the hydrograph and tailwater elevations used, and channel modifications downstream should be considered in the analysis and evaluation of the results of this investigation. Since only one recent prototype survey was available to use in the adjustment of the model, the initial conditions molded in the model for adjustment tests may have been different from the prototype conditions at that time. If the model had been molded to the prototype data for that time, the model results might have been somewhat different. The quantity of flow from the Black River and from the Mississippi River through Old River Diversion Canal could change the backwater effect and change considerably the movement of sediment in the cutoff.

55. In evaluating the results of tests of various plans, consideration should be given to the fact that some tests were continued through several repetitions of the hydrograph to give time for the channel to develop fully, while others had only one reproduction of the hydrograph. All tests were conducted with the 1967-68 hydrograph which was considered typical of this reach of the Red River. Prolonged or unusual low- or high-water periods could produce somewhat different results from those with this typical hydrograph.

56. Although several locks and dams are to be constructed upstream of this reach of the Red River that will affect the sediment load being transported into the test reach, no modification was made in the sediment load for model tests. The model did not reproduce sediment in suspension or the erosion of river banks (banks were fixed in the model). In spite of the limitations mentioned the adjustment of the model is considered sufficient to indicate trends that can be expected under conditions imposed for each plan and the relative effectiveness of such plans.

Results and Conclusions

57. The indications and conclusions developed from the results of model tests are summarized as follows:

a. The proposed overall channel was too wide to maintain a navigation channel of adequate width and depth above the Black River.

b. The development of an adequate navigation channel in the test reach would require a reduction in the width of the overall channel. This could be obtained with channel structures or by making the channel narrower and revetting its banks. The narrower channel with protected banks provided a smoother bank line and channel alignment.

c. Plan B with its longer radius curves would require less dike construction than Plan A, even though the cutoff would be longer and require more excavation. The longer radius curves of Plan B would make it easier for tows to navigate the limited width bends.

d. Structures will be required on the left bank downstream of the Black River to prevent a bar from developing along this bank that would prevent upbound tows from crossing to the left bank to align with the cutoff channel.

e. Structures will be required in the downstream entrance of the old bendway to provide an access channel into the old bendway for recreation. The most effective plan tested consisted of a longitudinal dike upstream of the bendway to an elevation that would allow flow but not sediment over it with a spur dike to top bank elevation downstream of the bendway to force the flow that had overtopped the longitudinal dike back into the river.

Table 1

Dike Location and Elevation, Plan A - Plan A-12

River Mile	Dike Type*	Bank Line	A Length ft**	A El†	A-1 Length ft	A-1 El	A-2 Length ft	A-2 El	A-3 Length ft	A-3 El	A-4 Length ft	A-4 El	A-5 Length ft	A-5 El
37.19	Spur	Left			270	30-25	270	30-25	270	30-25				
37.19	Vane	Left												
37.14	Vane	Left									400	35	400	[illegible]
37.10	(Long	Right												
	Tie)													
37.04	Long	Right									400	14	400	25
37.00	(Long	Right			(1,500	35	(1,500	35	(1,500	35				
	Tie)				200	35)	200	35)	200	35)				
36.93	Vane	Right									400	14	400	25
36.90	(L-	Right												
	Head)													
36.79	Spur	Right					220	25	220	25				
36.75	(I-	Right									(200	13	(200	25
	Head)										400	13)	400	25)
36.70	(L-	Right												
	Head)													
36.68	Spur	Right			300	30-25								
36.67	Spur	Right							200	25				
36.60	Vane	Right									350	13	350	25
36.60	(L-	Right												
	Head)													
36.59	Spur	Right					240	25	240	25				
36.53	(Spur,	Right												
	L-Head)													
36.44	Spur	Right			300	25-20								
36.43	Vane	Right									400	13	400	25
36.40	Spur	Right					200	25-15	200	25-15				
36.40	(L-	Right												
	Head)													
36.40	(Long	Left	1600	11	(1,600	35	(1,400	35	(1,400	35				
	Tie)				200	35)	200	35)	200	35)				
36.32	Spur	Right												
36.30	Long	Left												
36.29	Spur	Right												
36.28	Vane	Right									400	13	400	25
36.27	Long	Left									400	13	400	25
36.20	(L-	Left												
	Head)													
36.12	Vane	Left									350	13	350	25
36.10	Spur	Left			350	30-25	350	25-15	350	25-15				
36.00	(L-	Left												
	Head)													

River Mile	Dike Type*	Bank Line	A-6 Length ft	A-6 El	A-7 Length ft	A-7 El	A-8 Length ft	A-8 El	A-9 Length ft	A-9 El	A-10 Length ft	A-10 El	A-11 Length ft	A-11 El	A-12 Length ft	A-12 El
37.19	Spur	Left													150	20
37.19	Vane	Left	400	25	400	[illegible]										
37.14	Vane	Left														
37.10	(Long	Right					(1,000	50	(1,000	50	(1,000	50	(1,000	50	(1,000	50
	Tie)						200	50)	200	50)	200	50)	200	50)	200	50
37.04	Long	Right														
37.00	(Long	Right	800	35	800	35										
			400	28	400	28)										
	Tie)															
36.93	Vane	Right														
36.90	(L-	Right	(140	28	140	28	(140	35	(140	35	(140	35	(140	35	(140	35
	Head)		400	28)	400	28)	400	35)	400	35)	400	35)	400	35)	400	35)
36.79	Spur	Right														
36.75	(I-	Right														
	Head)															
36.70	(L-	Right	(140	24	(140	24	(140	35	(140	35	(140	35	(140	35	(140	35
	Head)		400	28)	400	28)	400	35)	400	35)	400	35)	400	35)	400	35)
36.68	Spur	Right														
36.67	Spur	Right														
36.60	Vane	Right														
36.60	(L-	Right	(150	20	(150	20										
	Head)		400	28)	400	28)										
36.59	Spur	Right														
36.53	(Spur,	Right							100	25	100	25	100	25	100	25
	L-Head)														200	25
36.44	Spur	Right														
36.43	Vane	Right														
36.40	Spur	Right											100	20	100	20
36.40	(L-	Right	(100	20	(100	20										
	Head)		400	28)	400	28)										
36.40	(Long	Left	(750	35	(750	35										
			400	28)	400	28										
	Tie)															
36.32	Spur	Right									100	20				
36.30	Long	Left							650	35	650	35	650	35	650	35
															[illegible]	[illegible]
36.29	Spur	Right														
36.28	Vane	Right														
36.27	Long	Left														
36.20	(L-	Left	100	28	100	28										
	Head)		400	28	400	28)										
36.12	Vane	Left														
36.10	Spur	Left							[illegible]							
36.00	(L-	Left	100	24	100	24										
	Head)		400	28)	400	28)										

(Continued)

Note: Two closure dikes were installed to el 50 across the upstream entrance to the old bendway.
* Long indicates longitudinal dike. Parentheses indicate one continuous dike.
** Top distance is for bank or upstream end. Bottom distance is for channel or downstream.
† Elevation in feet NGVD. Top or first elevation is for bank or upstream end. Bottom or second elevation is for channel or downstream end.

Table [illegible] (Concluded)

River Mile	Dike Type*	Bank Line	A Length ft**	A Ft	A-1 Length ft	A-1 Ft	A-2 Length ft	A-2 Ft	A-3 Length ft	A-3 Ft	A-4 Length ft	A-4 Ft	A-5 Length ft	A-5 Ft	A-6 Length ft	A-6 Ft	A-7 Length ft	A-7 Ft
35.96	(	Left									250	[illegible]	[illegible]	[illegible]				
	Head)										400	[illegible]	[illegible]	[illegible]				
36.93	Spur	Left																
35.90	(L	Left													[illegible]	[illegible]	[illegible]	[illegible]
	Head)														400	28	400	28
35.89	Spur	Left			350	30-25	350	25-15	350	25-15								
35.82	Vane	Left									350	12	350	25				
35.78	Spur	Left																
35.70	Spur	Left			350	30-25	350	25-15	350	25-15								
35.70	(L	Left													(100	28	(100	28
	Head)														400	28)	100	28)
35.66	Vane	Left									400	12	400	25				
35.62	Spur	Left																
35.51	(L-	Left									(250	22-12	250	25				
	Head)										400	12)	400	25)				
35.50	Spur	Left			350	30-25	350	25-15	350	25-15								
35.50	(L-	Left													(100	24	(100	24
	Head)														400	28)	400	28)
35.45	Spur	Left																
35.40	(L-	Left													(100	20	(100	20
	Head)														400	28)	400	28)
35.36	Vane	Left									400	12	400	25				
35.33	Spur	Left			350	30-25	350	25-15	350	25-15								
35.30	Spur	Left																
35.20	(Long	Right	1300	10	(1,300	35	(1,300	35	(1,300	35					(550	35	(550	35
															400	28)	400	28)
	Tie)				200	35)	200	35)	200	35)								
35.20	Vane	Left									400	12	400	25				
35.20	(L-	Left													(100	28	(100	28
	Head)														400	28)	400	28)
35.10	(L-	Left													(50	28	(50	28
	Head)														400	28)	400	28)
35.10	Long	Right																
35.05	Long	Right									400	12	400	25				
35.04	Vane	Left									400	12	400	25				
34.97	Spur	Right																
34.94	Vane	Right									400	12	400	25				
34.90	Spur	Right																
34.90	(Spur,	Right			(300	30-25	300	25-15	300	25-15					(100	28	(100	28
	L Head)				240	25)									400	28)	400	28)
34.80	Spur	Right																
34.80	(L-	Right													(100	24	(100	28
	Head)														400	28)	400	28
34.78	(L-	Right									(100	[illegible]	(100	25				
	Head)										200	5	400	25)				
34.70	Spur	Right			300	25	300	25-15	300	25-15								
34.70	Long	Right			250	25	250	30	250	30			250	30	250	30	250	30
34.69	Vane	Right									400	12						
34.69	Spur	Right																
34.50	(Spur,	Right			600	40	(510	40	510	40			600	[illegible]	(600	40	(600	40
	L Head)						150	40)	150	40)			200	40	200	40)	200	40)
34.48	Vane	Right									400	12						
34.30	[illegible]	Right													(100	28	(100	28
	Head)														400	28	400	28)
34.10	Spur	Left																
34.04	Spur	Left																
33.98	Spur	Left																

River Mile	Dike Type*	A-8 Length ft	A-8 Ft	A-9 Length ft	A-9 Ft	[illegible] Length ft	[illegible] Ft	[illegible] Length ft	[illegible] Ft	[illegible] Length ft	[illegible] Ft
35.96	(										
	Head)										
36.93	Spur			[illegible]							
35.90	(L										
	Head)										
35.89	Spur										
35.82	Vane										
35.78	Spur			[illegible]	[illegible]						
35.70	Spur										
35.70	(L										
	Head)										
35.66	Vane										
35.62	Spur			200	25						
35.51	(L-										
	Head)										
35.50	Spur										
35.50	(L-										
	Head)										
35.45	Spur			100	25						
35.40	(L-										
	Head)										
35.36	Vane										
35.33	Spur										
35.30	Spur			100	25						
35.20	(Long										
	Tie)										
35.20	Vane										
35.20	(L-										
	Head)										
35.10	(L-										
	Head)										
35.10	Long			300	35						
35.05	Long										
35.04	Vane										
34.97	Spur			100	25						
34.94	Vane										
34.90	Spur			100	25						
34.90	(Spur,										
	L Head)										
34.80	Spur			100	[illegible]						
34.80	(L-										
	Head)										
34.78	(L-										
	Head)										
34.70	Spur										
34.70	Long	300	30	300	30	300	30	300	30	300	30
34.69	Vane										
34.69	Spur									100	30
34.50	(Spur,	(600	40	(600	40	600	40	600	40	(600	40
	L Head)	200	40)	200	40)	200	40	200	40)	200	40)
34.48	Vane										
34.30	[illegible]										
	Head)										
34.10	Spur			150	23	150	23	150	23	150	23
34.04	Spur			250	20	250	[illegible]	250	20	250	20
33.98	Spur			400	[illegible]	400	17	400	17	400	17

Table 2

Dike Location and Elevation, Plan B - Plan B-8

River Mile	Dike Type*	Bank	B Length ft	B El**	B-1 Length ft	B-1 El	B-2 Length ft	B-2 El	B-3 Length ft	B-3 El	B-4 Length ft	B-4 El	B-5 Length ft	B-5 El	B-6 Length ft	B-6 El	B-7 Length ft	B-7 El	B-8 Length ft	B-8 El
[illegible]	Long	Left			950	45	950	45	950	45	950	45	950	45	950	45	950	45	950	45
[illegible]	Spur	Right			150	30	150	30	150	30	150	30	150	30	150	30	150	30	150	30
36.8	Spur	Left			350	30	350	30	350	30	350	30	350	30	350	30	350	30	350	30
[illegible]	Spur	Left			400	30	400	30	400	30	400	30	400	30	400	30	400	30	400	30
36.6	Spur	Left			400	30	400	30	400	30	400	30	400	30	400	30	400	30	400	30
36.5	Spur	Left			350	30	350	30	350	30	350	30	350	30	350	30	350	30	350	30
36.4	Spur	Left					350	30	350	30	350	30	350	30	350	30	350	30	350	30
35.5	Long	Right									800	35	800	35	800	35	800	35	800	35
34.1	(T-	Left											(135	20	(135	20	(135	20	(135	20
	Head)												720	20)	720	20)	720	20)	720	20)
34.0	Spur	Left									400	20								

Note: Two closure dikes were installed to el 50 across the upstream entrance to the old bendway.

* Long indicates longitudinal dike. Parentheses indicate one continuous dike.

** Elevation in feet NGVD. Top elevation is bank or upstream. Bottom elevation is channel or downstream.

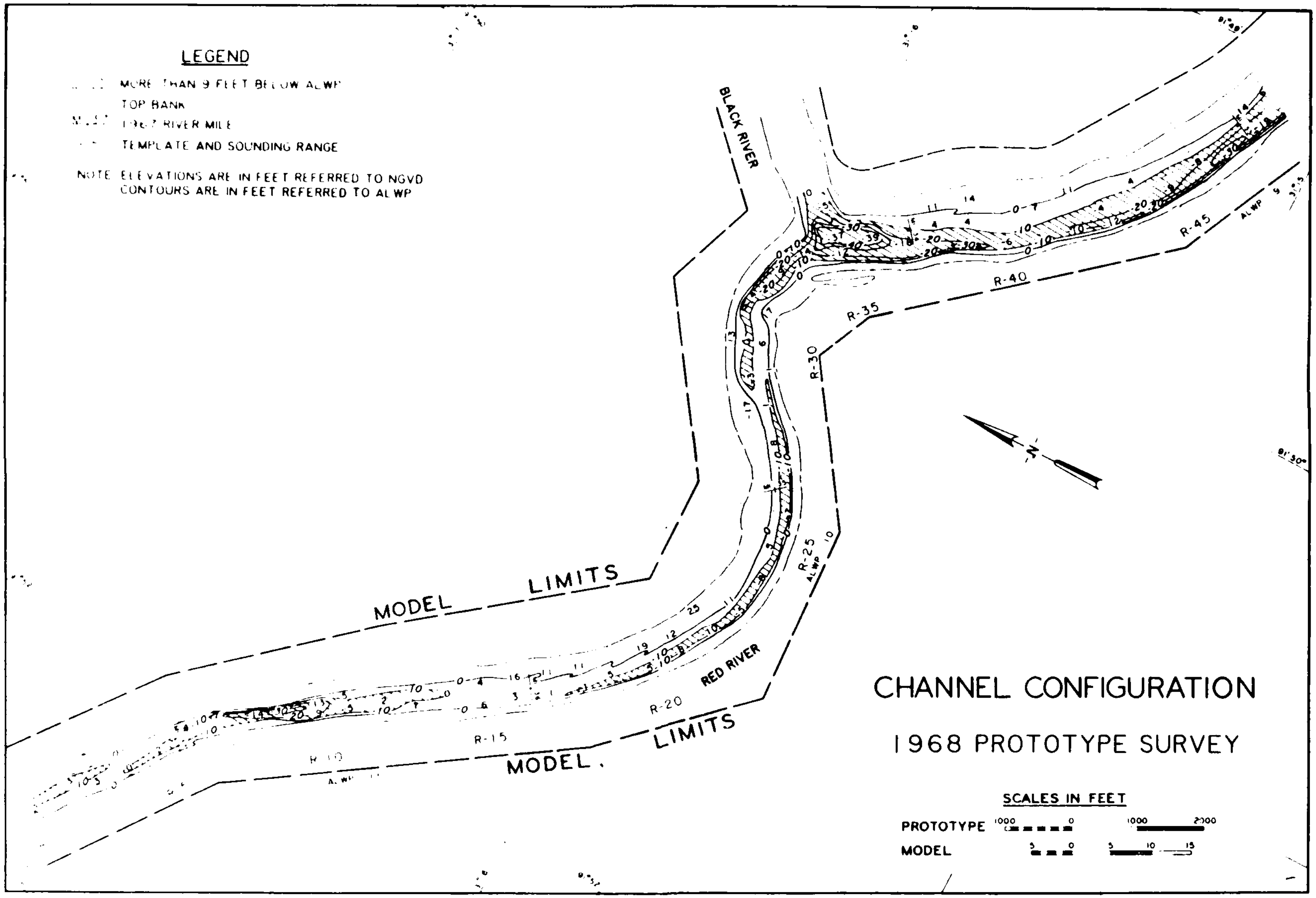
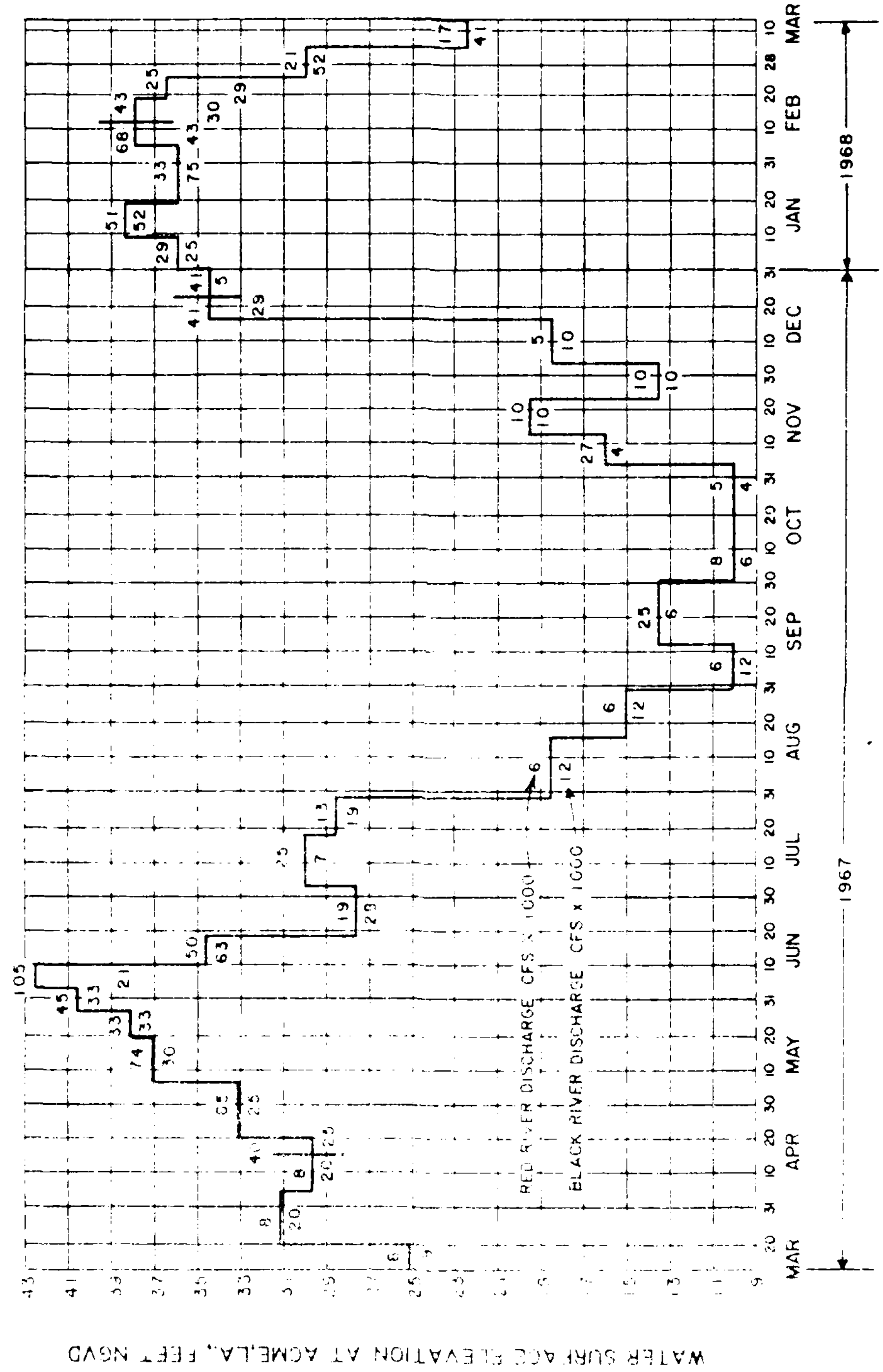
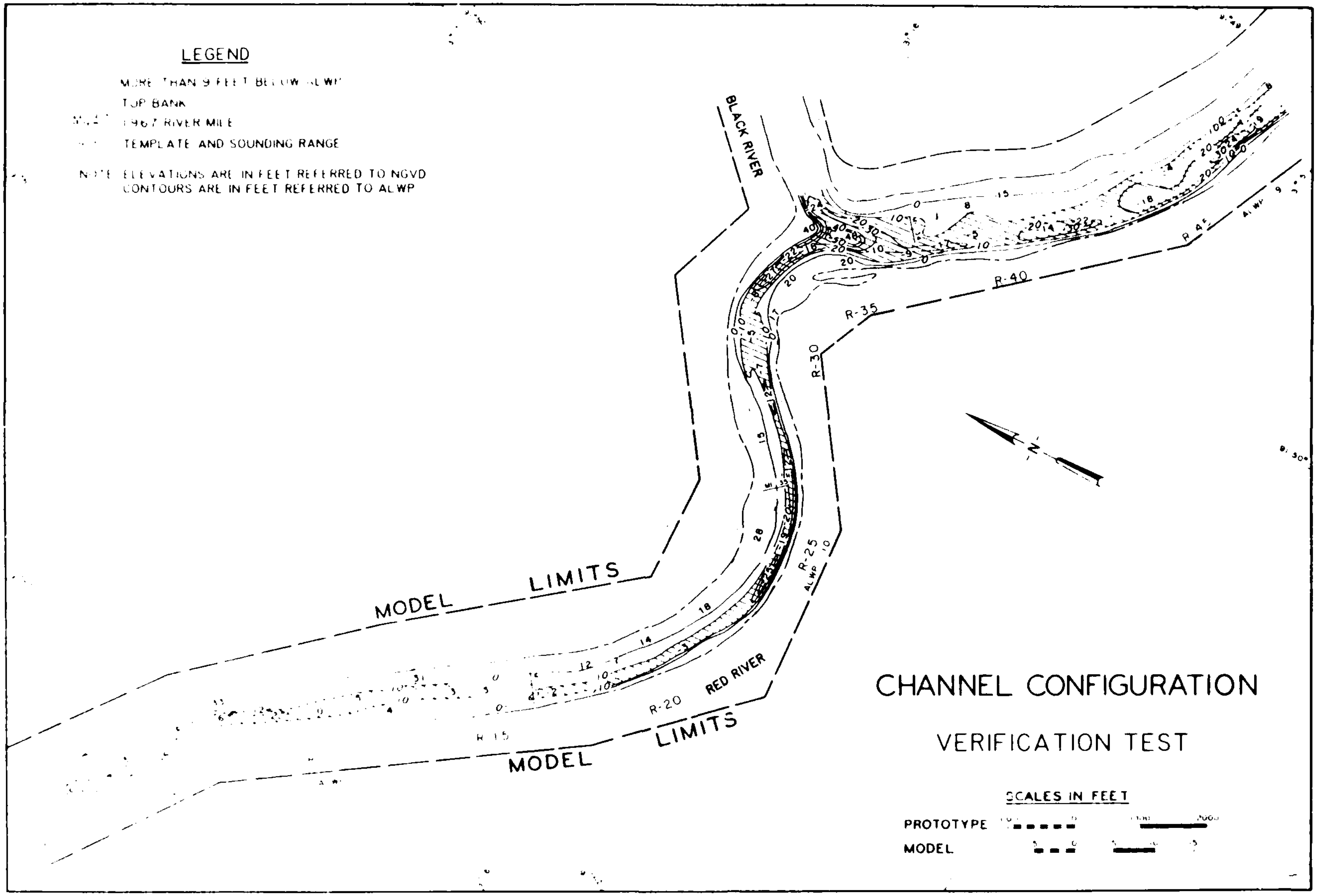

LEGEND
MORE THAN 9 FEET BELOW ALWP
TOP BANK
1967 RIVER MILE
TEMPLATE AND SOUNDING RANGE
NOTE: ELEVATIONS ARE IN FEET REFERRED TO NGVD
CONTOURS ARE IN FEET REFERRED TO ALWP
BLACK RIVER
RED RIVER
MODEL LIMITS
MODEL LIMITS
R-10
R-15
R-20
R-25
R-30
R-35
R-40
R-45
N
CHANNEL CONFIGURATION
1968 PROTOTYPE SURVEY
SCALES IN FEET
PROTOTYPE 1000 0 1000 2000
MODEL 5 0 5 10 15

PLATE 1

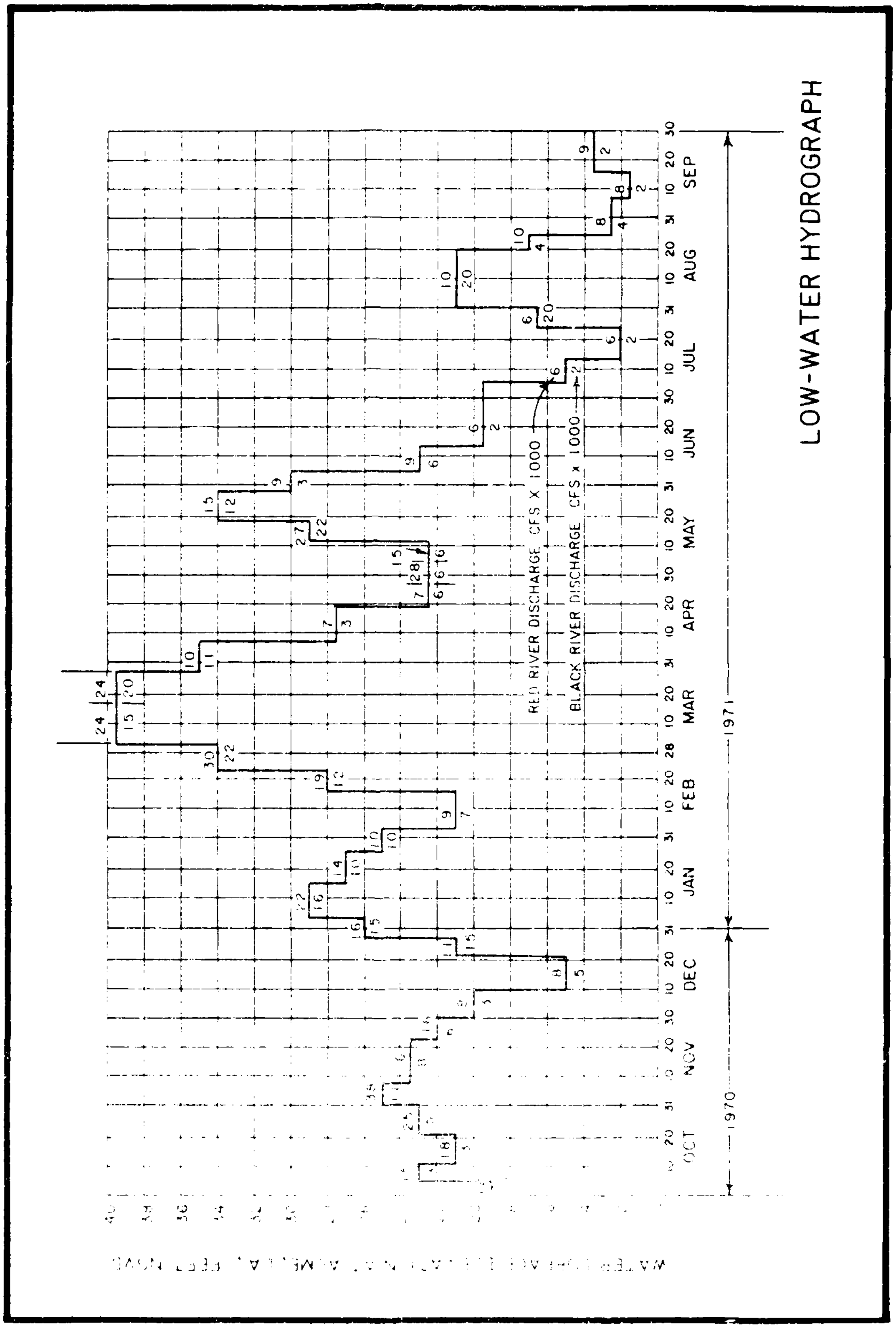


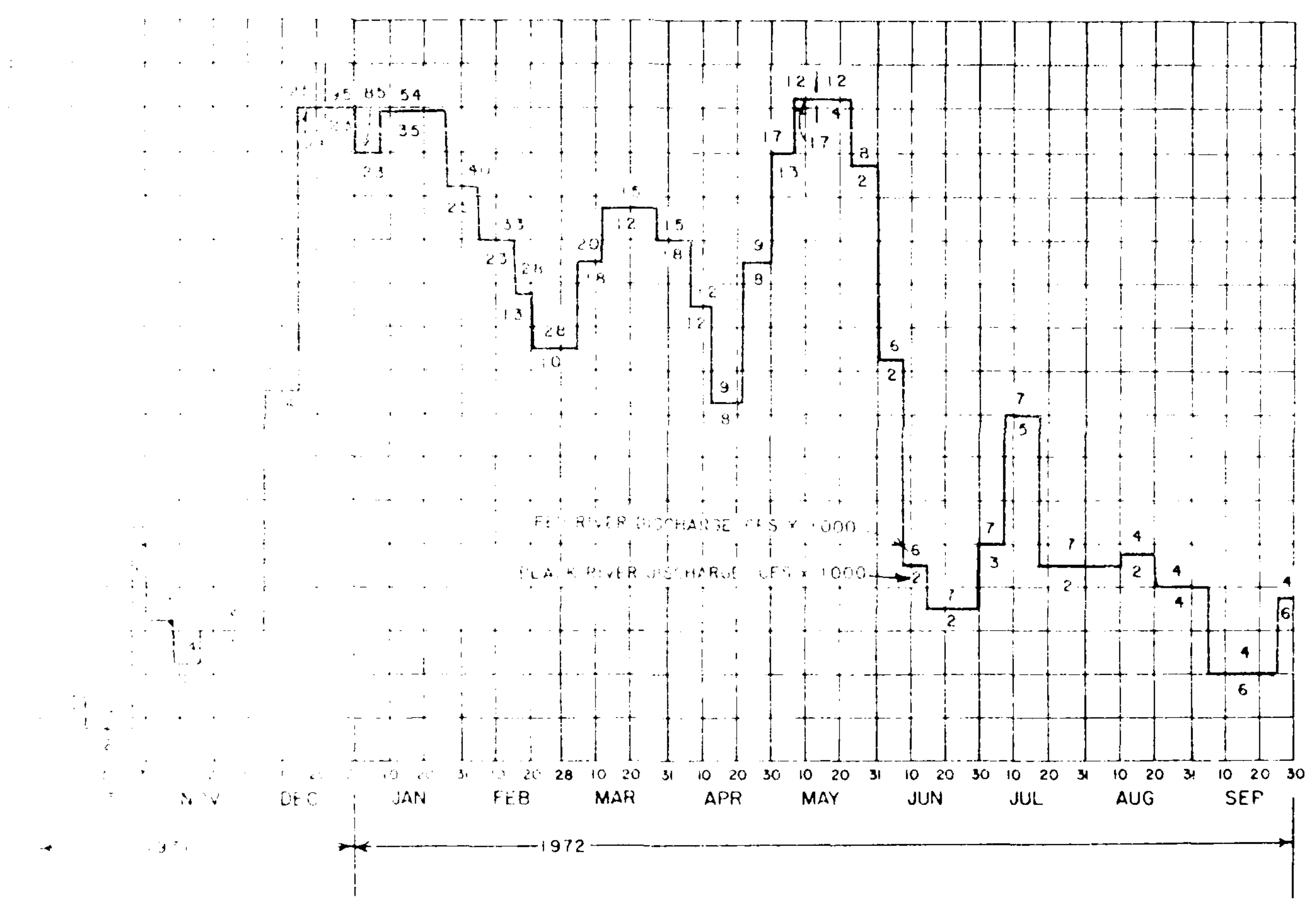
ADJUSTMENT HYDROGRAPH



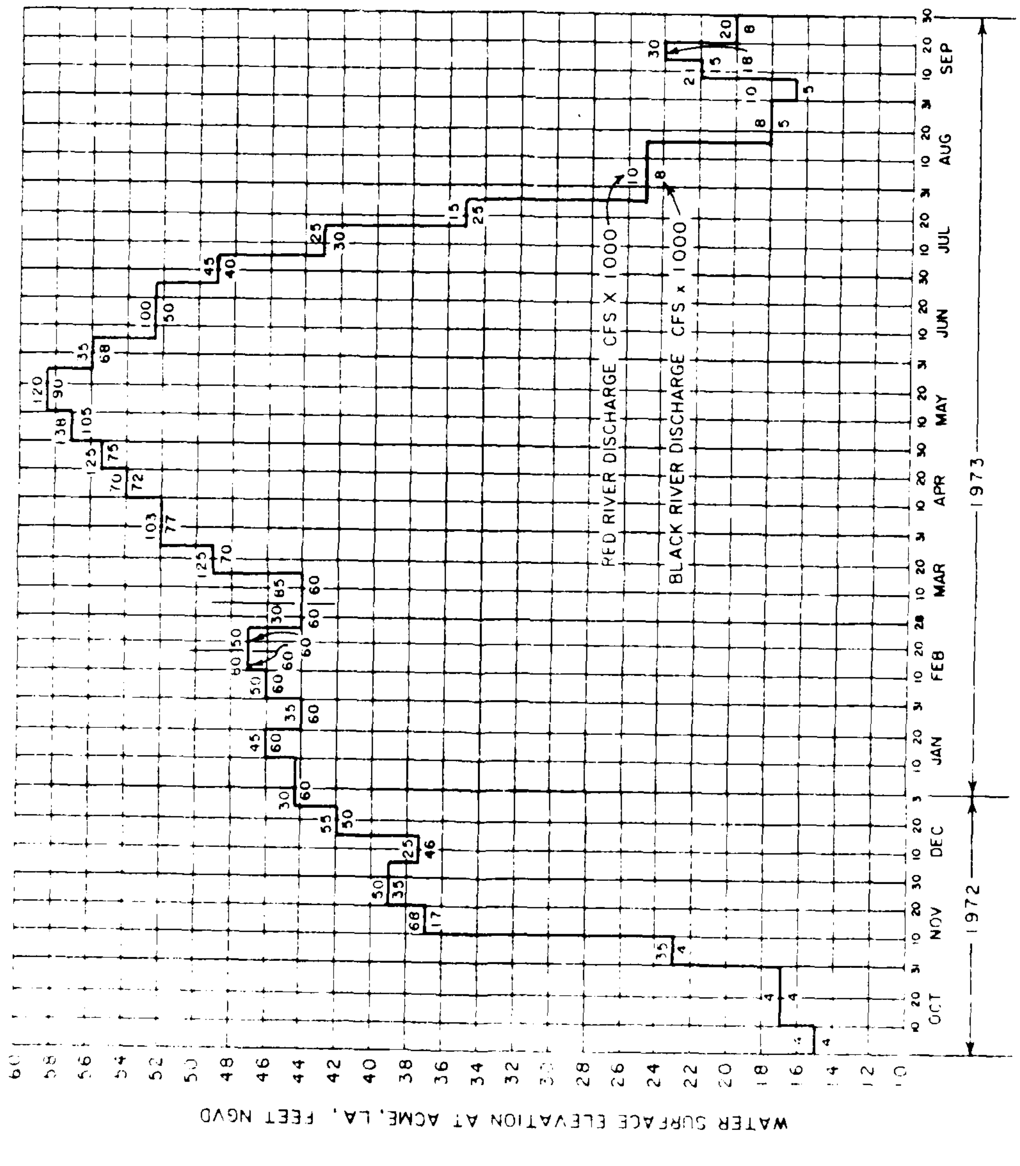
CHANNEL CONFIGURATION

VERIFICATION TEST


LOW-WATER HYDROGRAPH
RED RIVER DISCHARGE CFS X 1000
BLACK RIVER DISCHARGE CFS x 1000
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
1970
1971

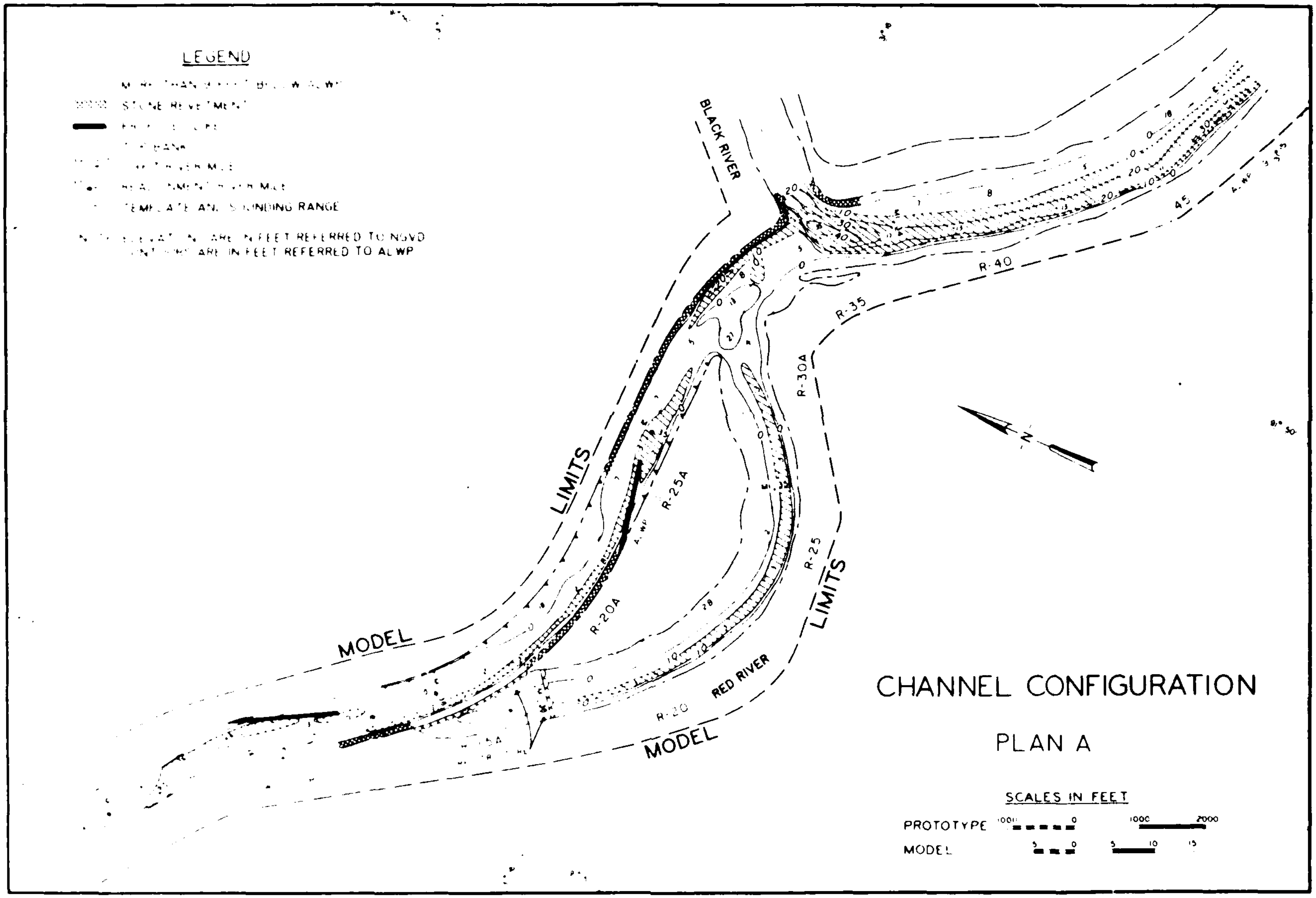


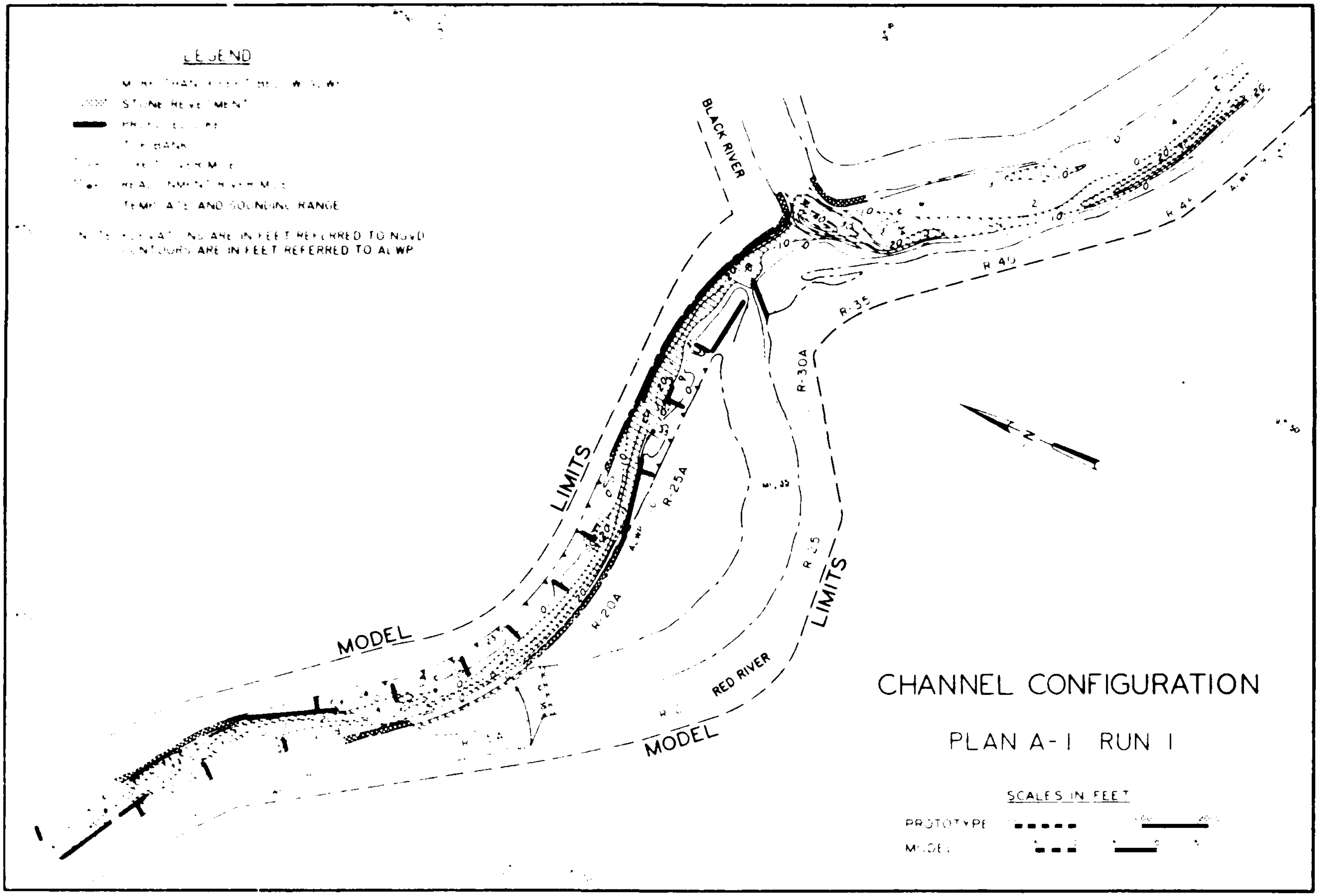
AVERAGE HYDROGRAPH

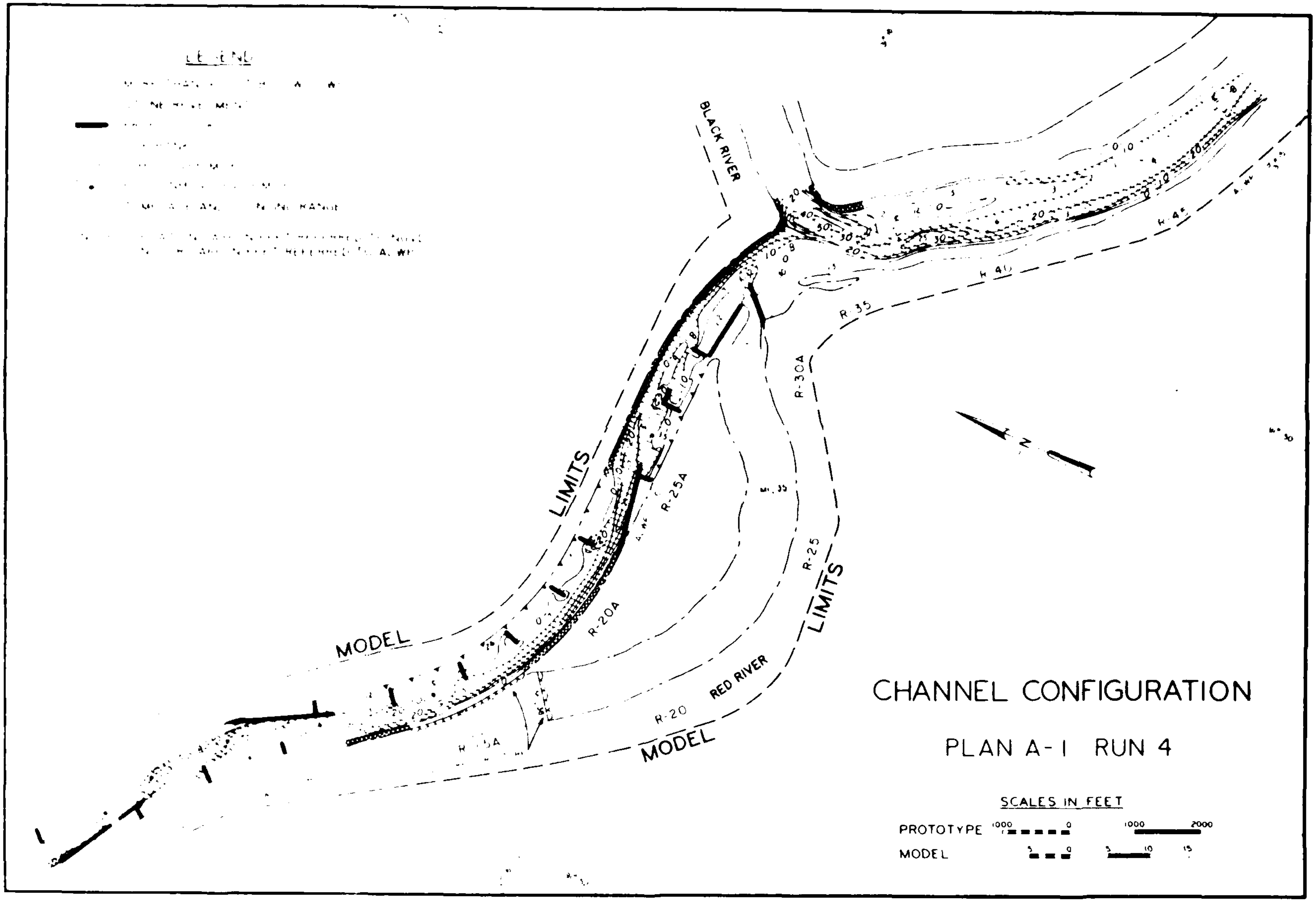


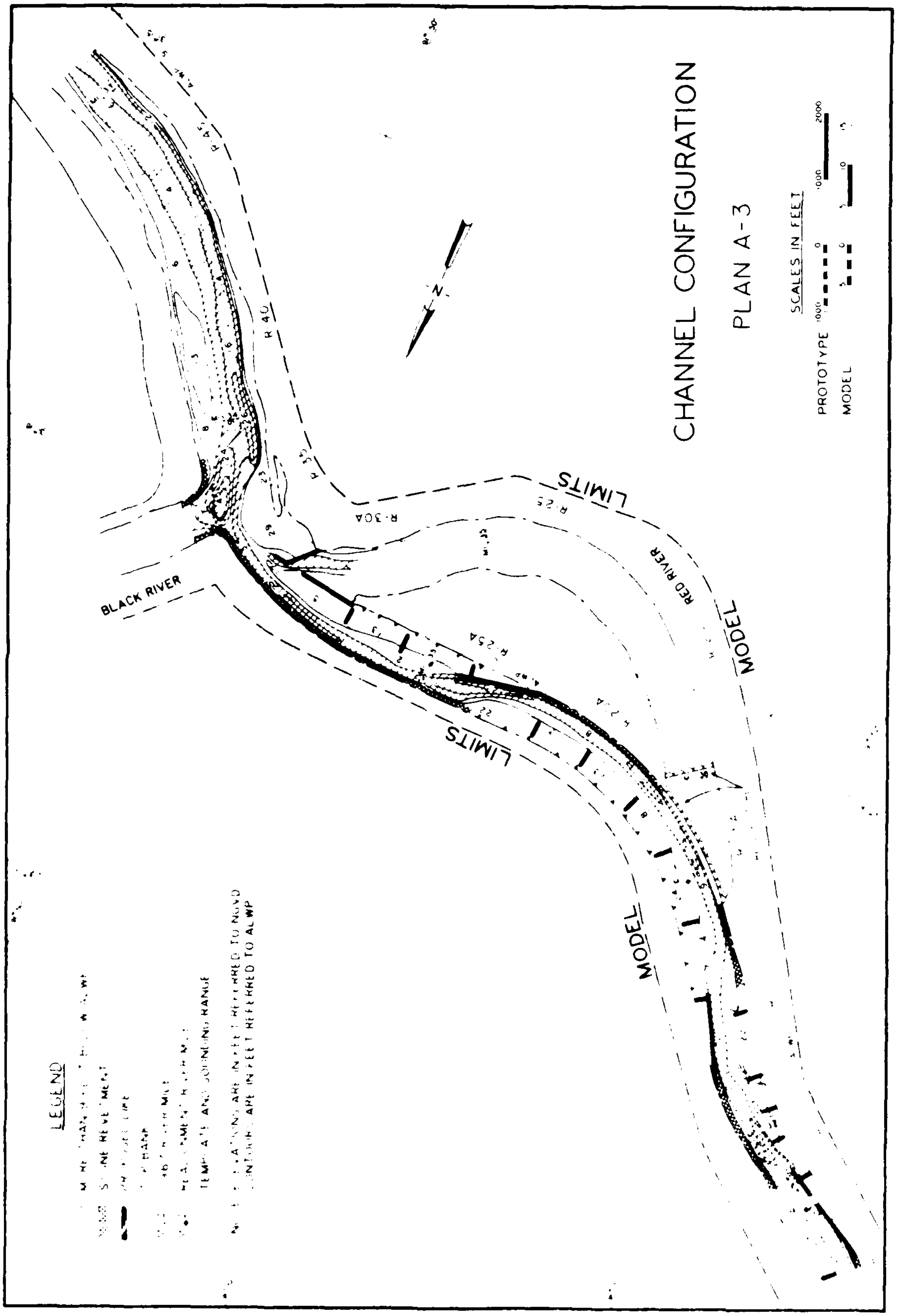
HIGH-WATER HYDROGRAPH

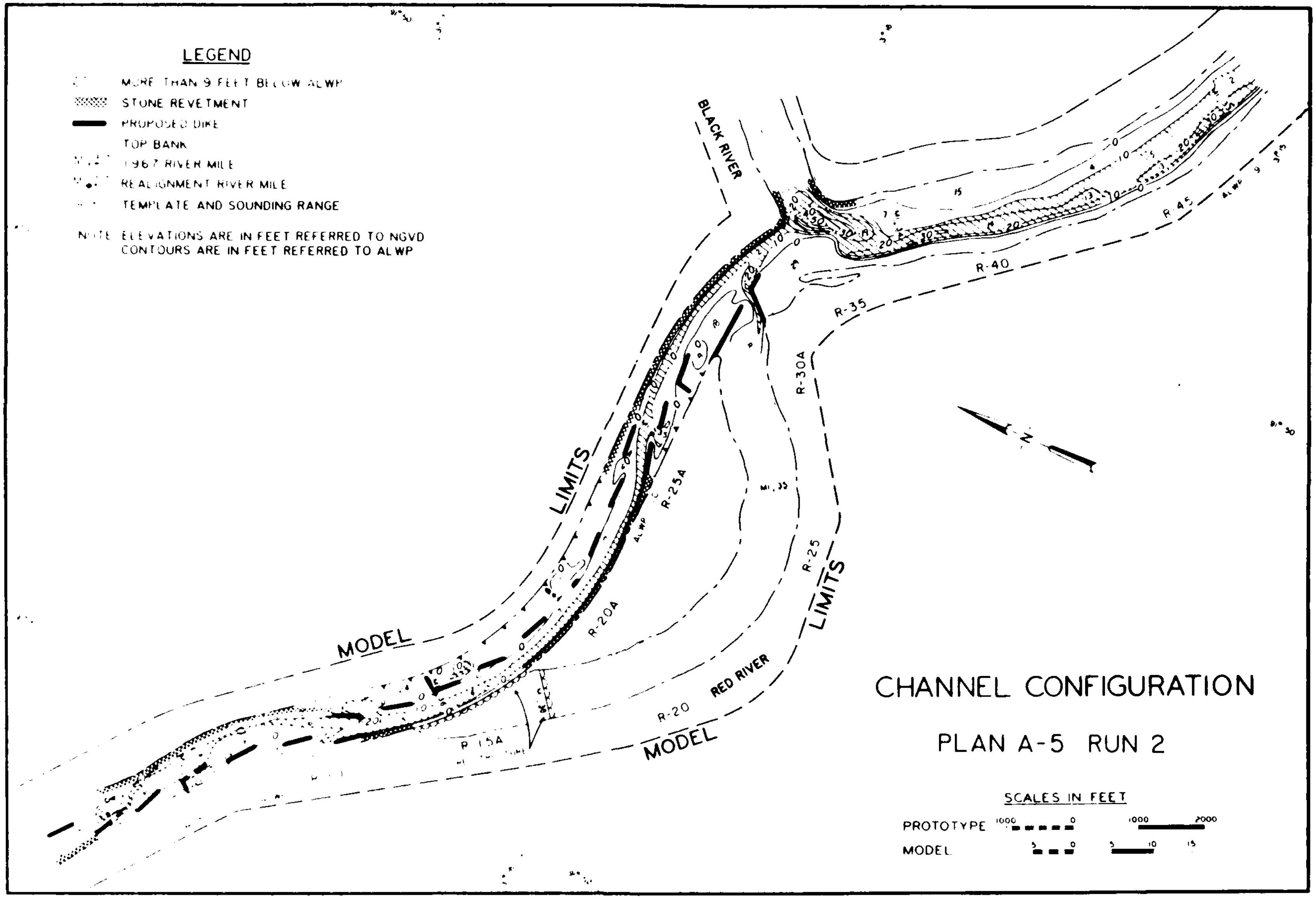
PLATE 6


LEGEND
STONE REVETMENT
BLACK RIVER
RED RIVER
LIMITS
MODEL
LIMITS
MODEL
R-40
R-35
R-30A
R-25A
R-25
R-20A
R-20
45
CHANNEL CONFIGURATION
PLAN A
SCALES IN FEET
PROTOTYPE
MODEL


LEGEND
STONE REVETMENT
TEMPLATE AND SOUNDING RANGE
CONTOURS ARE IN FEET REFERRED TO ALWP
BLACK RIVER
RED RIVER
MODEL LIMITS
MODEL LIMITS
R-40
R-35
R-30A
R-25A
R-25
R-20A
CHANNEL CONFIGURATION
PLAN A-1 RUN 1
SCALES IN FEET
PROTOTYPE
MODEL

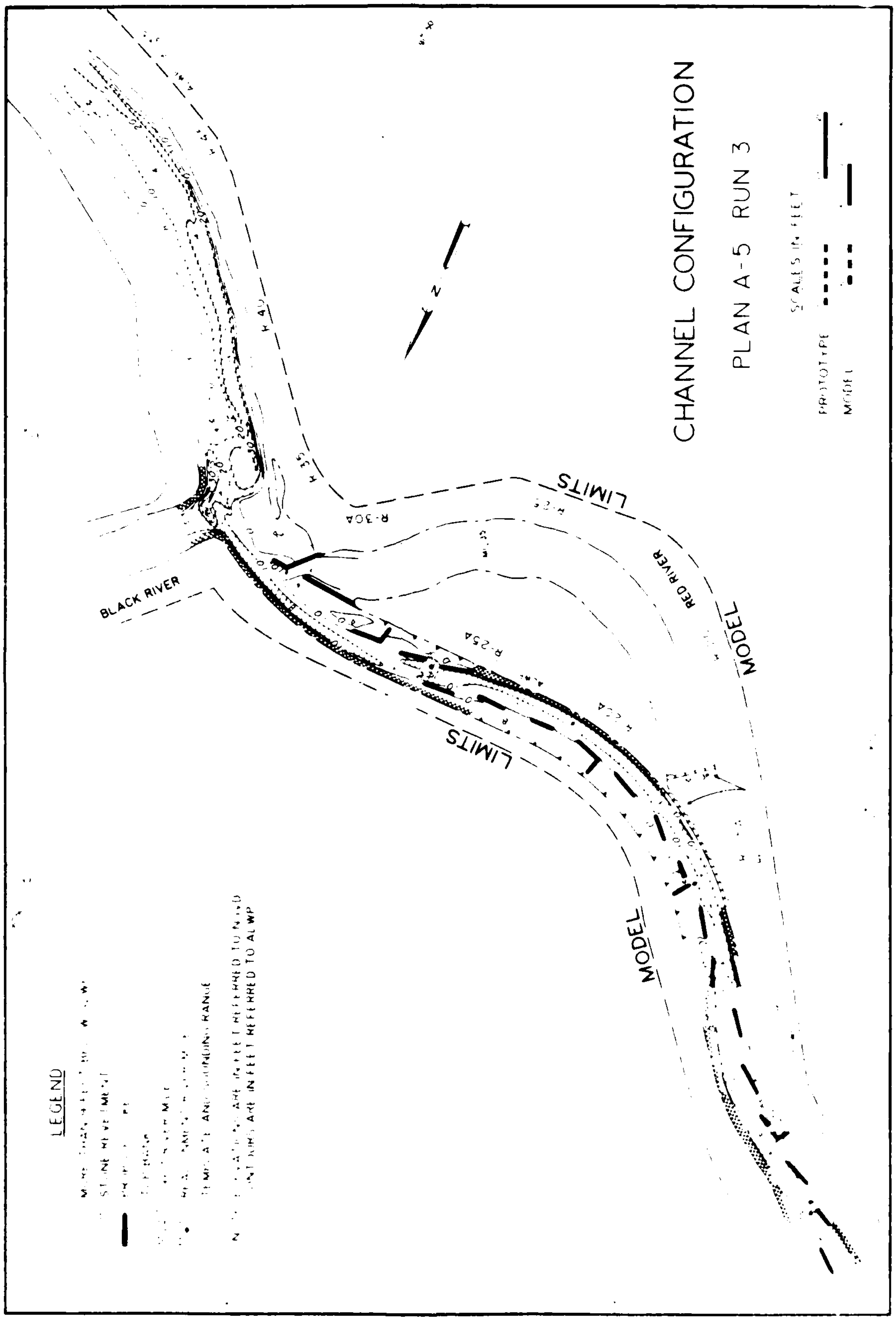

BLACK RIVER
RED RIVER
LIMITS
MODEL
LIMITS
MODEL
R-35
R-40
R-45
R-30A
R-25
R-25A
R-20A
R-20
CHANNEL CONFIGURATION
PLAN A-1 RUN 4
SCALES IN FEET
PROTOTYPE 1000 0 1000 2000
MODEL 5 0 5 10 15

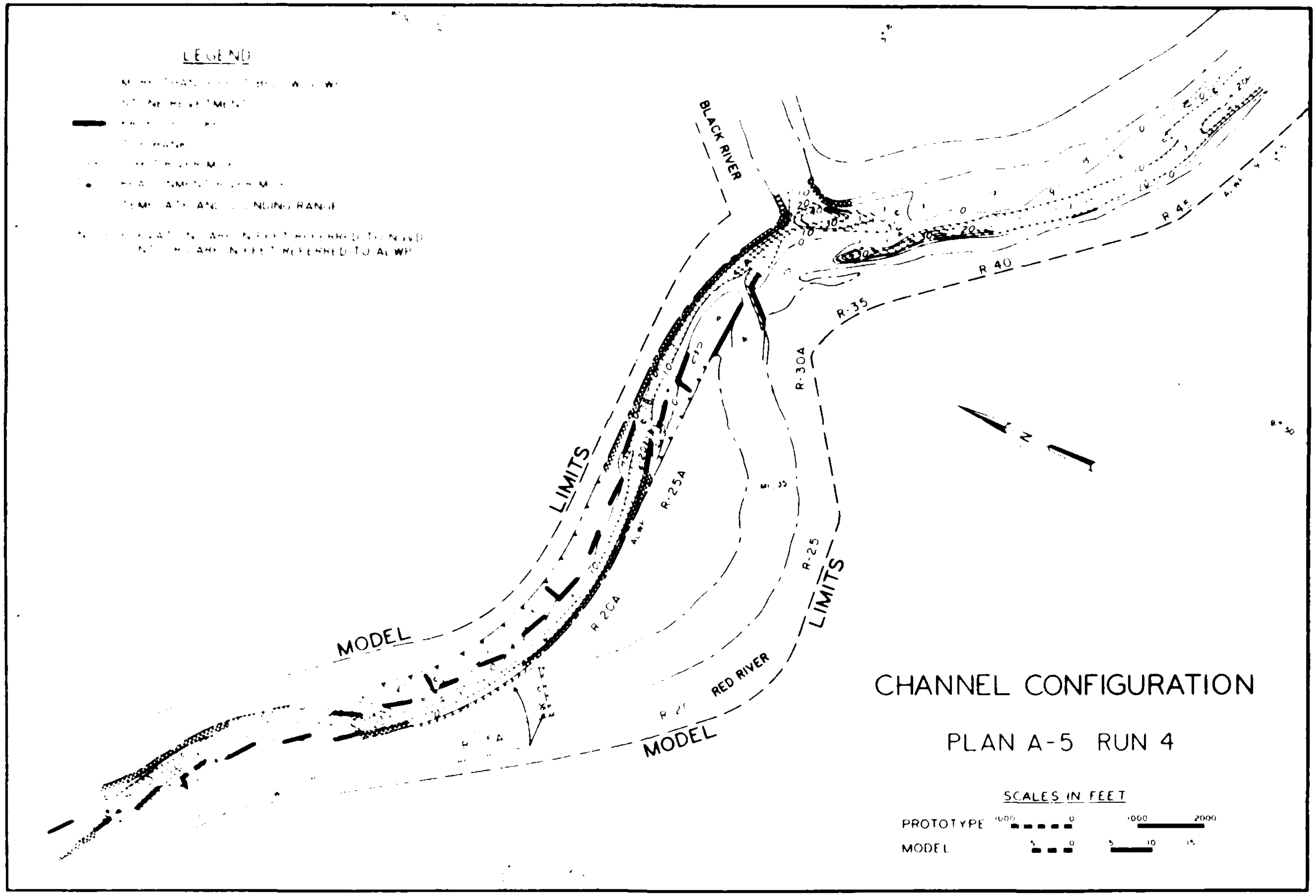

CHANNEL CONFIGURATION
PLAN A-3
SCALES IN FEET
PROTOTYPE 1000 0 1000 2000
MODEL 5 0 5 10 15
BLACK RIVER
RED RIVER
MODEL LIMITS
MODEL LIMITS
R-30A
R-25A
LEGEND
STONE REVETMENT
TEMPLATE AND SOUNDING RANGE

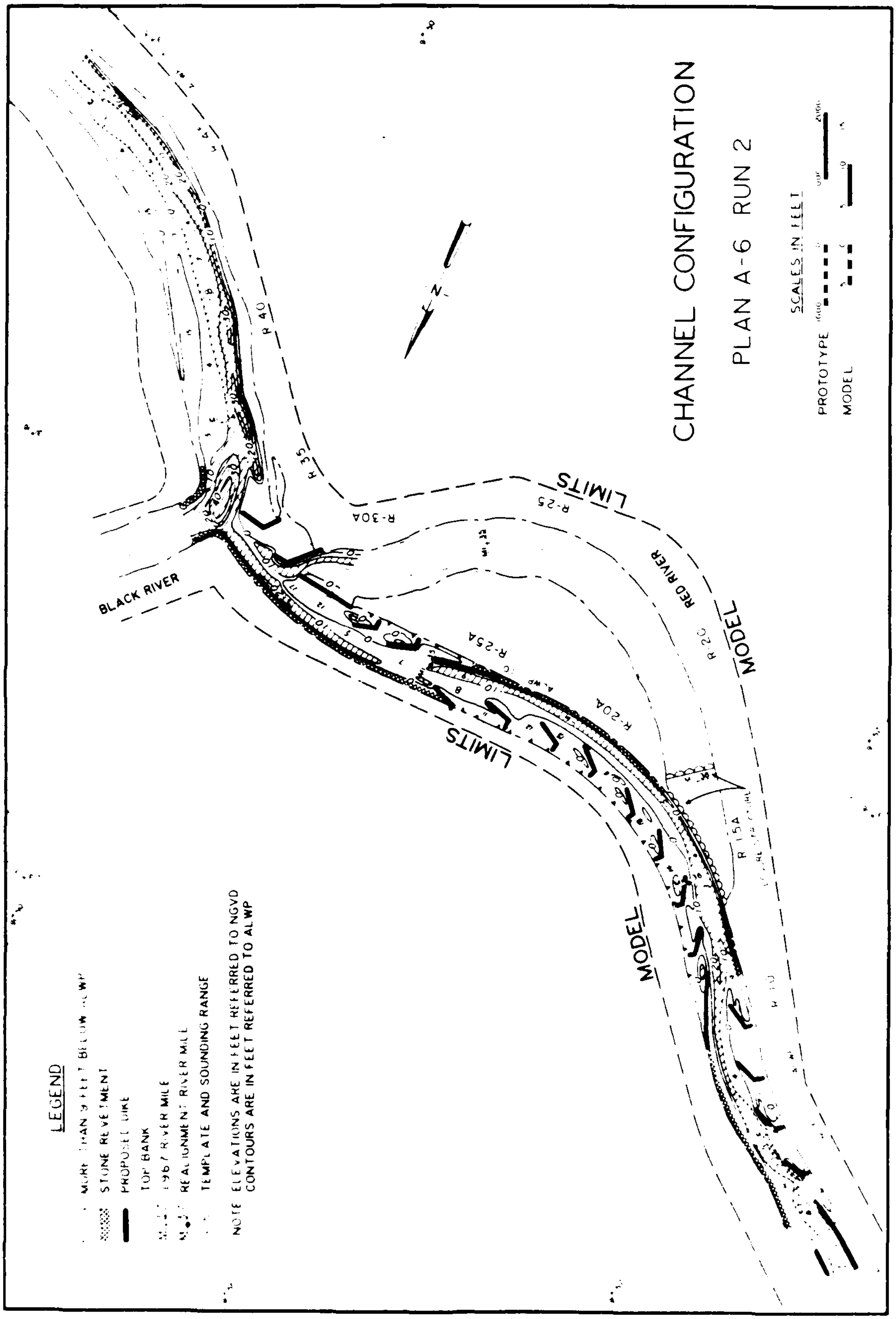


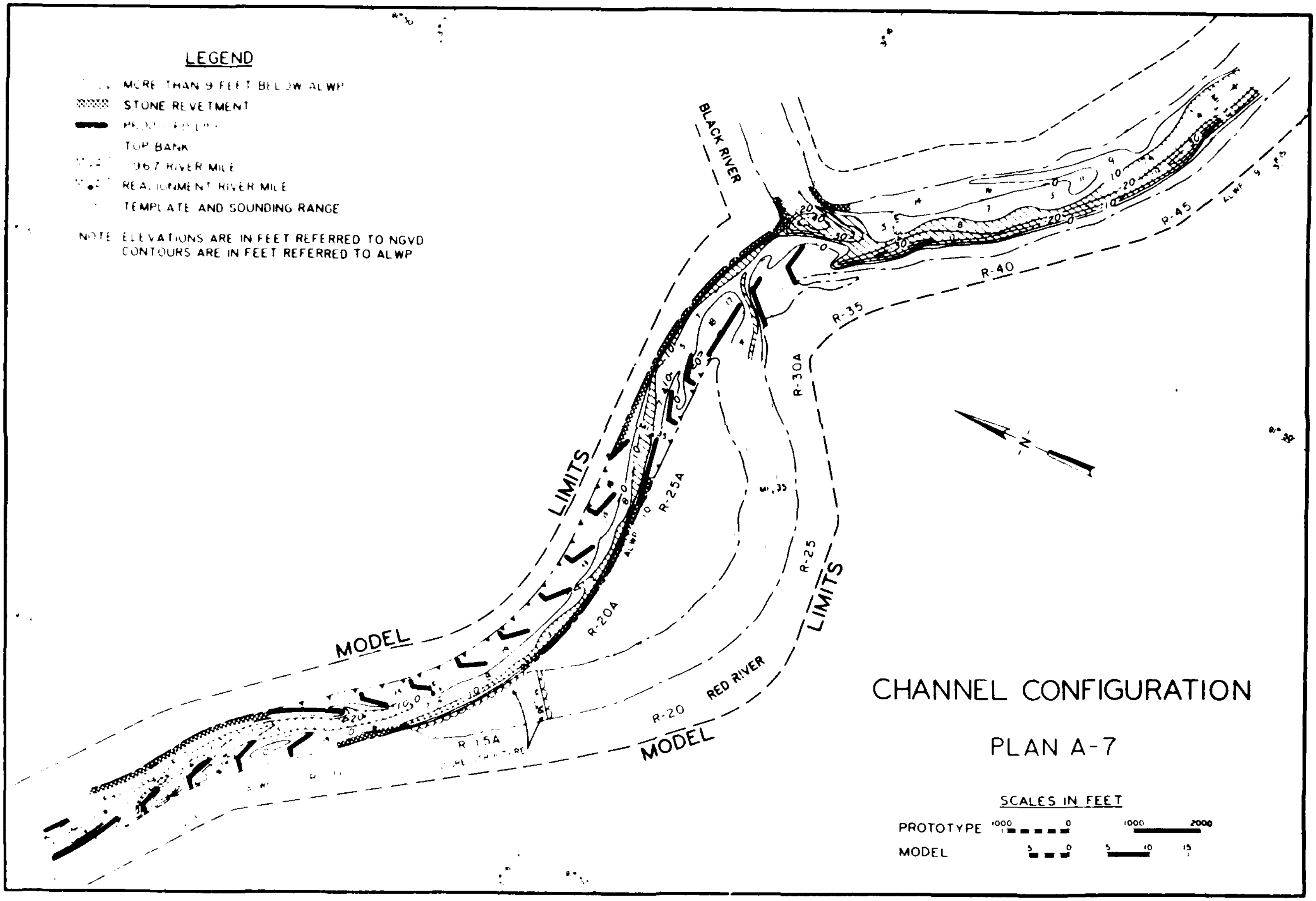
CHANNEL CONFIGURATION

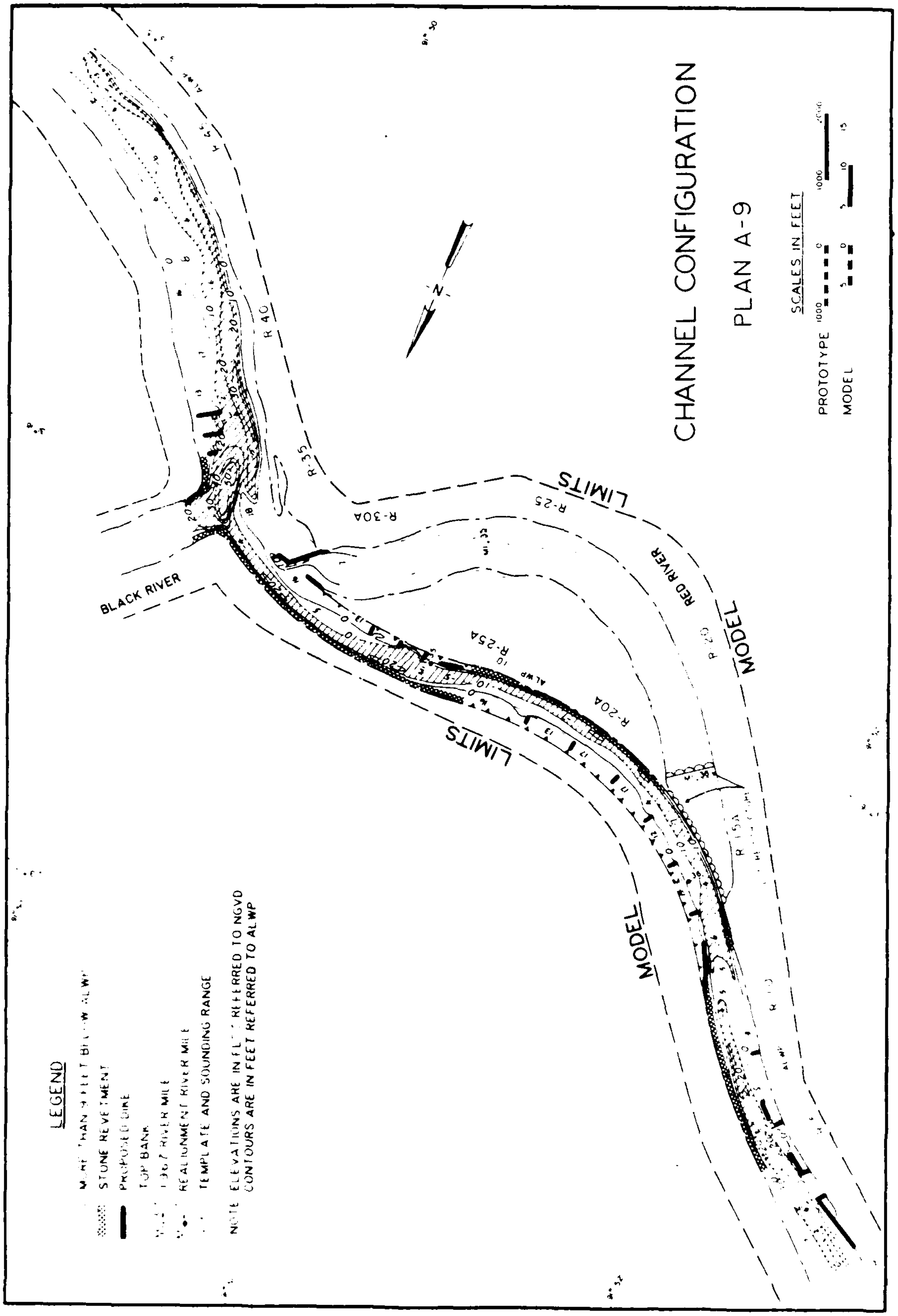
PLAN A-5 RUN 2

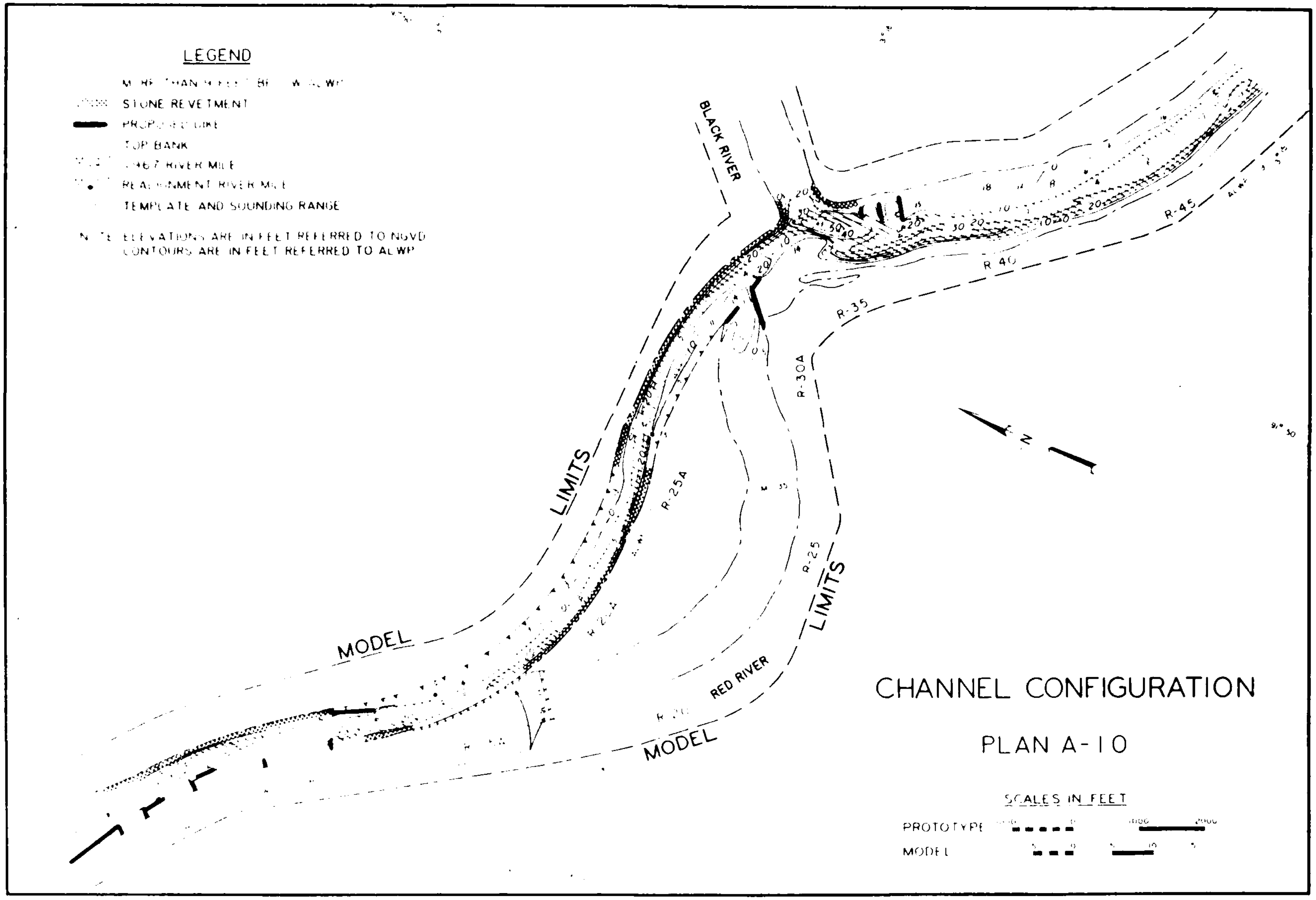

CHANNEL CONFIGURATION
PLAN A-5 RUN 3
SCALES IN FEET
PROTOTYPE
MODEL
LEGEND
BLACK RIVER
RED RIVER
MODEL
LIMITS
MODEL
LIMITS
R-30A
R-25A

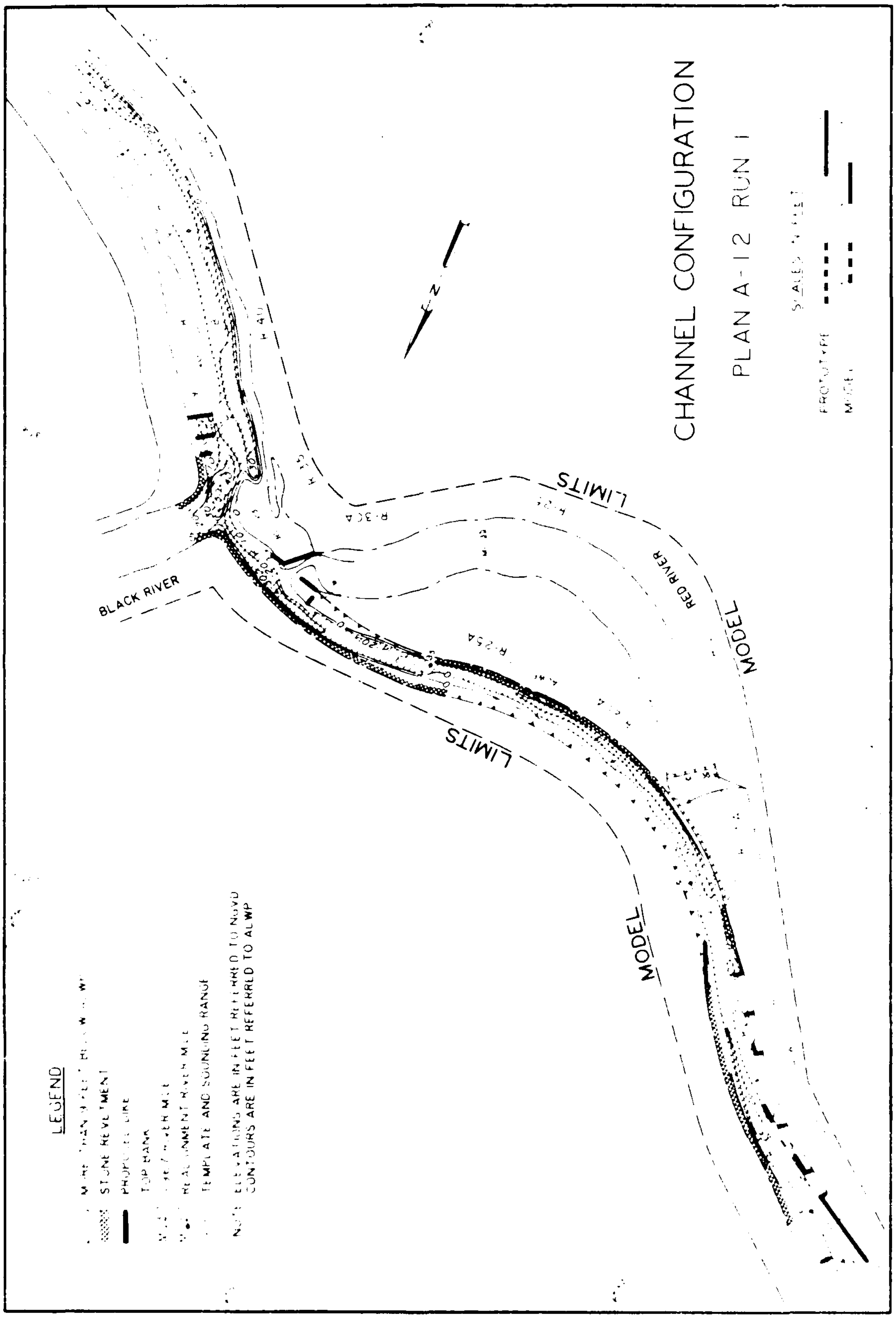

LEGEND
BLACK RIVER
LIMITS
MODEL
R-45
R-40
R-35
R-30A
R-25A
R-25
R-20A
RED RIVER
N
CHANNEL CONFIGURATION
PLAN A-5 RUN 4
SCALES IN FEET
PROTOTYPE 1000 0 1000 2000
MODEL 5 0 5 10 15

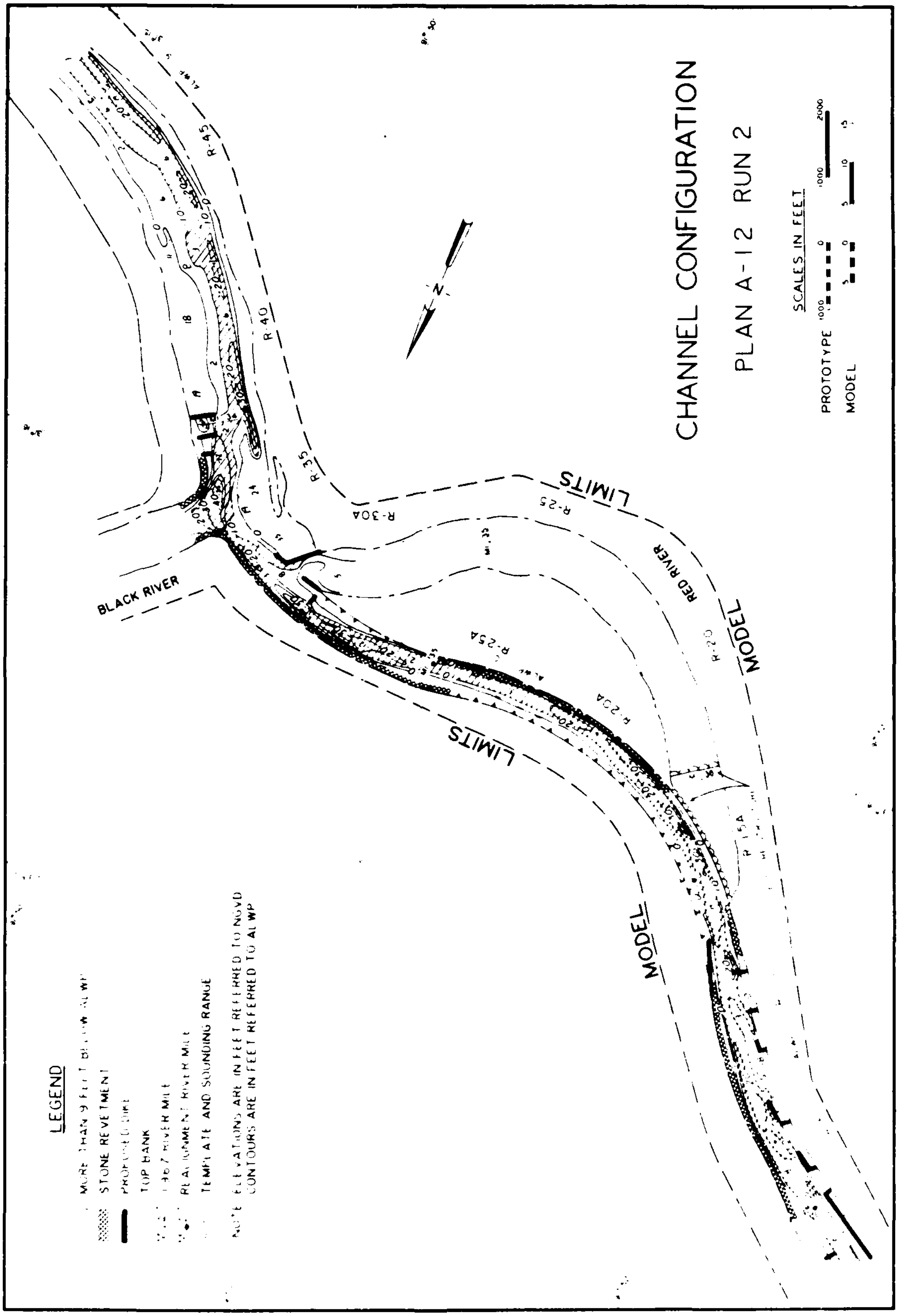

CHANNEL CONFIGURATION
PLAN A-6 RUN 2
SCALES IN FEET
PROTOTYPE
MODEL
LEGEND
STONE REVETMENT
PROPOSED DIKE
TOP BANK
1967 RIVER MILE
REALIGNMENT RIVER MILE
TEMPLATE AND SOUNDING RANGE
NOTE: ELEVATIONS ARE IN FEET REFERRED TO NGVD
CONTOURS ARE IN FEET REFERRED TO ALWP
BLACK RIVER
RED RIVER
LIMITS
MODEL
LIMITS
MODEL
R-30A
R-25A
R-20A
R-25
R 35
R 40
R 15A
R 10
R 20

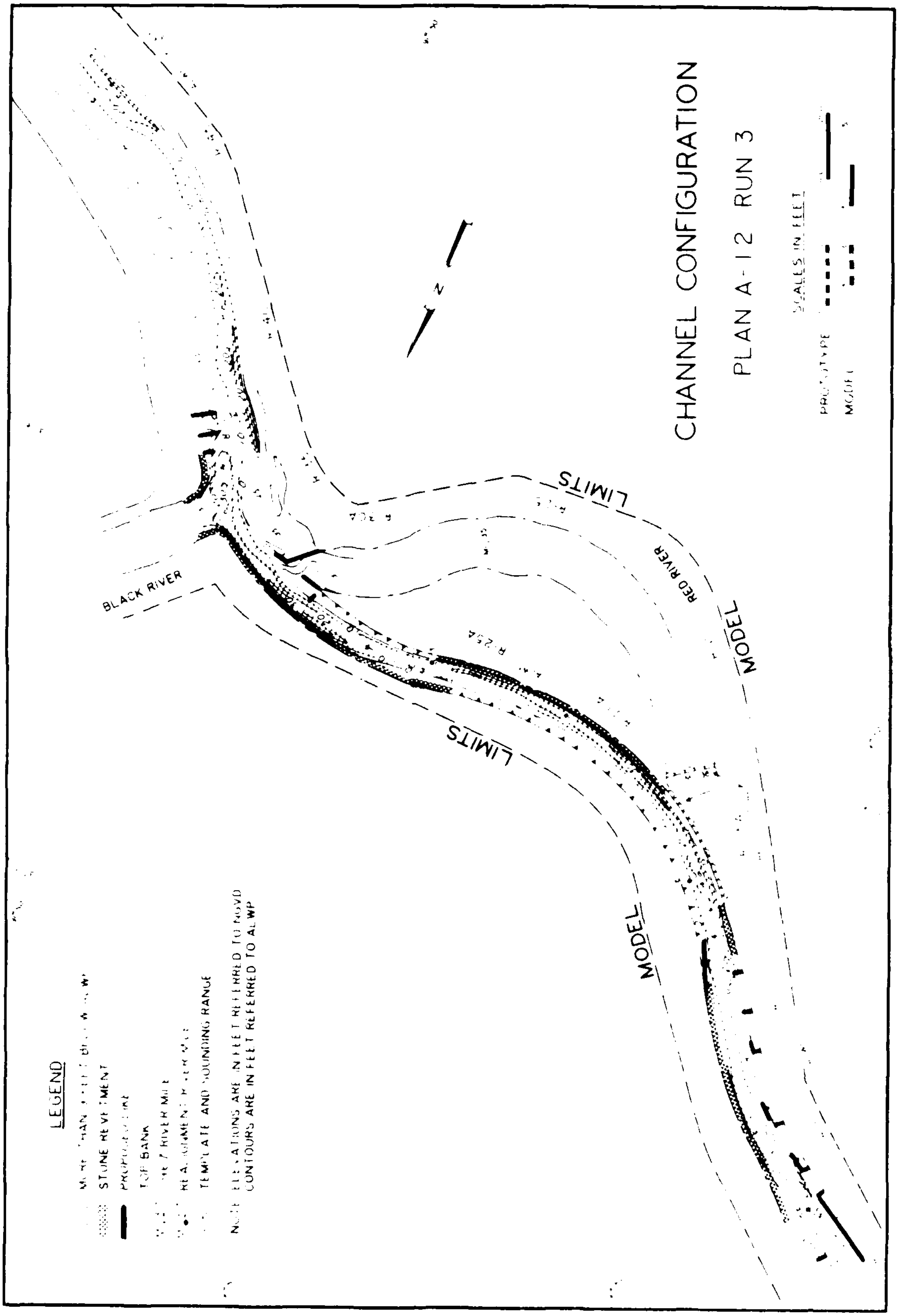

LEGEND
MORE THAN 9 FEET BELOW ALWP
STONE REVETMENT
TOP BANK
1967 RIVER MILE
REALIGNMENT RIVER MILE
TEMPLATE AND SOUNDING RANGE
NOTE: ELEVATIONS ARE IN FEET REFERRED TO NGVD
CONTOURS ARE IN FEET REFERRED TO ALWP
BLACK RIVER
RED RIVER
MODEL LIMITS
MODEL LIMITS
R-45
R-40
R-35
R-30A
R-25A
R-25
R-20A
R-20
R-15A
ALWP
N
CHANNEL CONFIGURATION
PLAN A-7
SCALES IN FEET
PROTOTYPE 1000 0 1000 2000
MODEL 5 0 5 10 15

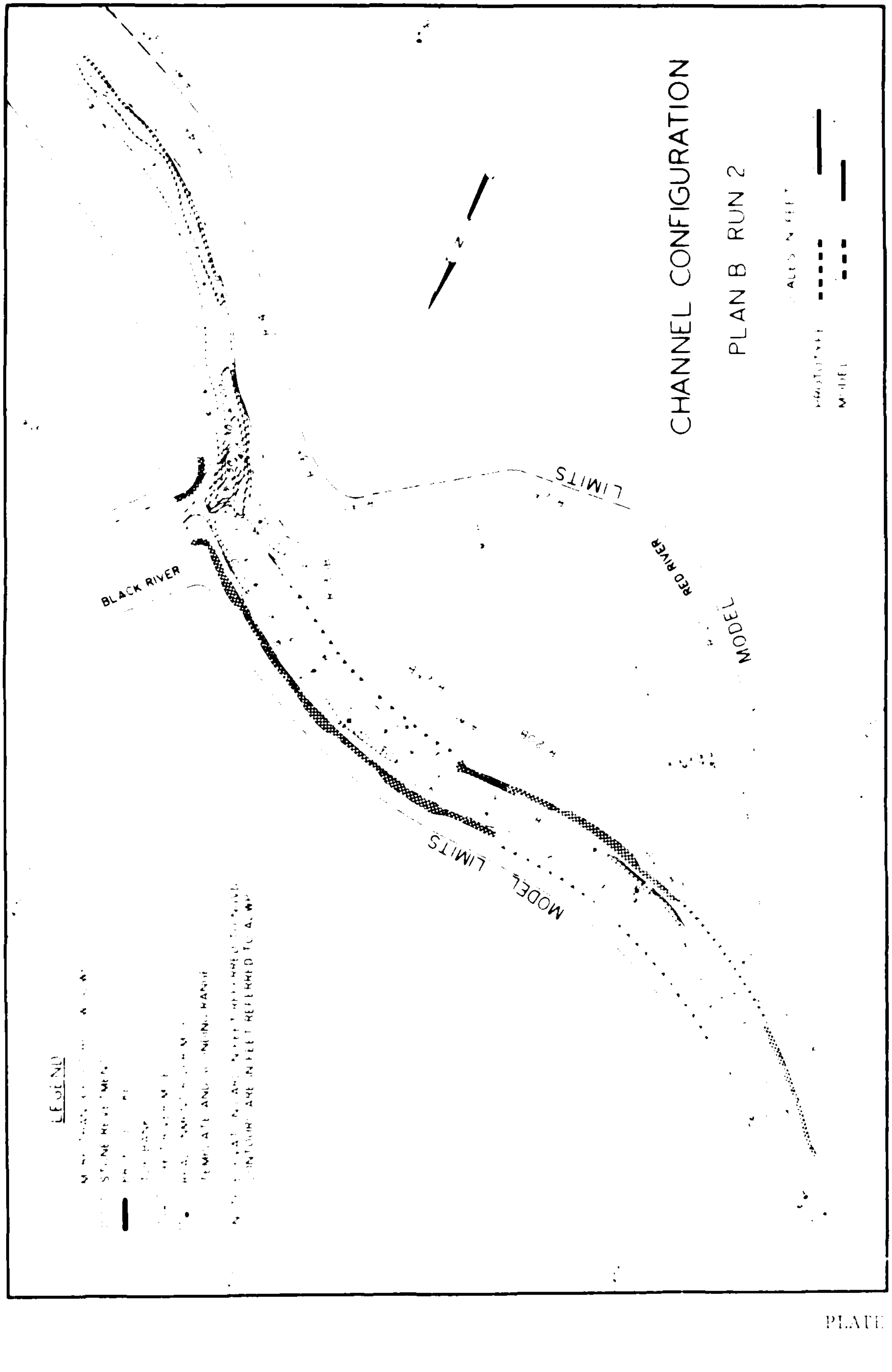

CHANNEL CONFIGURATION
PLAN A-9
SCALES IN FEET
PROTOTYPE
MODEL
LEGEND
STONE REVETMENT
PROPOSED DIKE
TOP BANK
REALIGNMENT RIVER MILE
TEMPLATE AND SOUNDING RANGE
CONTOURS ARE IN FEET REFERRED TO ALWP
BLACK RIVER
RED RIVER
MODEL
LIMITS
MODEL
LIMITS
R-40
R-35
R-30A
R-25
R-25A
R-20A
R-20
R-15A

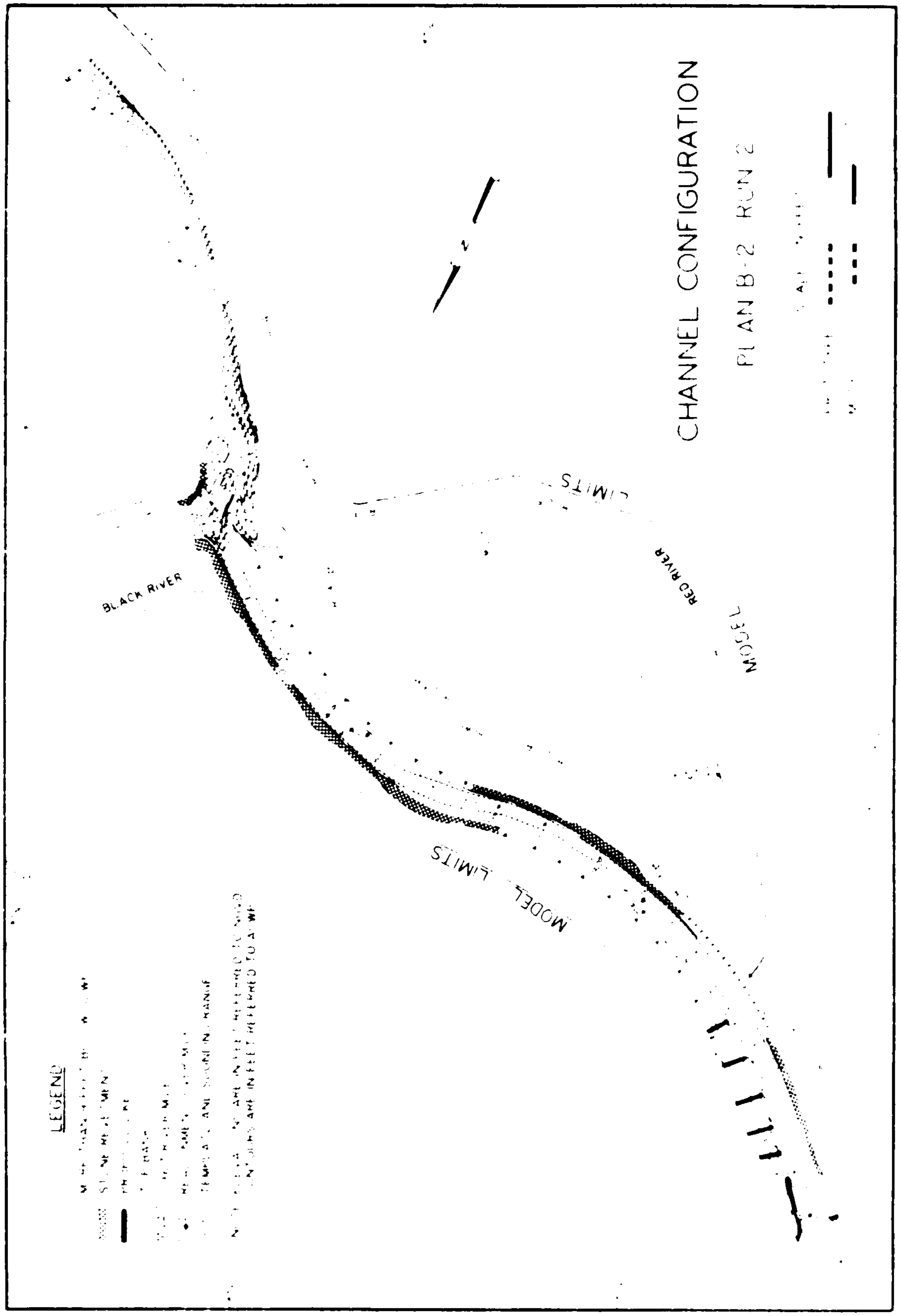

LEGEND
STONE REVETMENT
TOP BANK
TEMPLATE AND SOUNDING RANGE
CONTOURS ARE IN FEET REFERRED TO ALWP
BLACK RIVER
RED RIVER
LIMITS
MODEL
R-45
R 40
R-35
R-30A
R-25A
R-25
CHANNEL CONFIGURATION
PLAN A-10
SCALES IN FEET
PROTOTYPE
MODEL

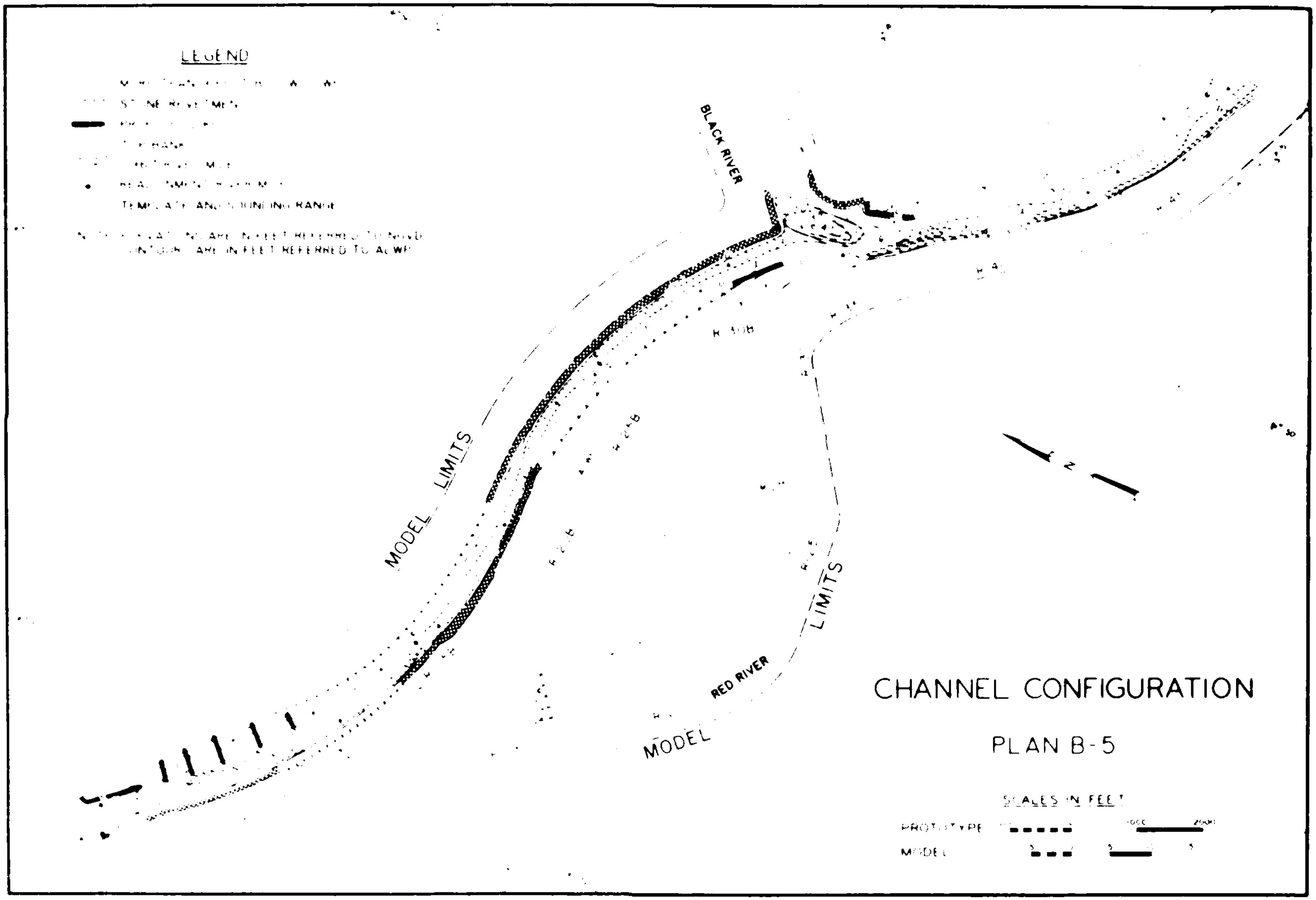

CHANNEL CONFIGURATION
PLAN A-12 RUN 1
BLACK RIVER
RED RIVER
MODEL
LIMITS
MODEL
LIMITS
LEGEND
STONE REVETMENT
TOP BANK
TEMPLATE AND SOUNDING RANGE
NOTE: ELEVATIONS ARE IN FEET REFERRED TO NGVD
CONTOURS ARE IN FEET REFERRED TO ALWP

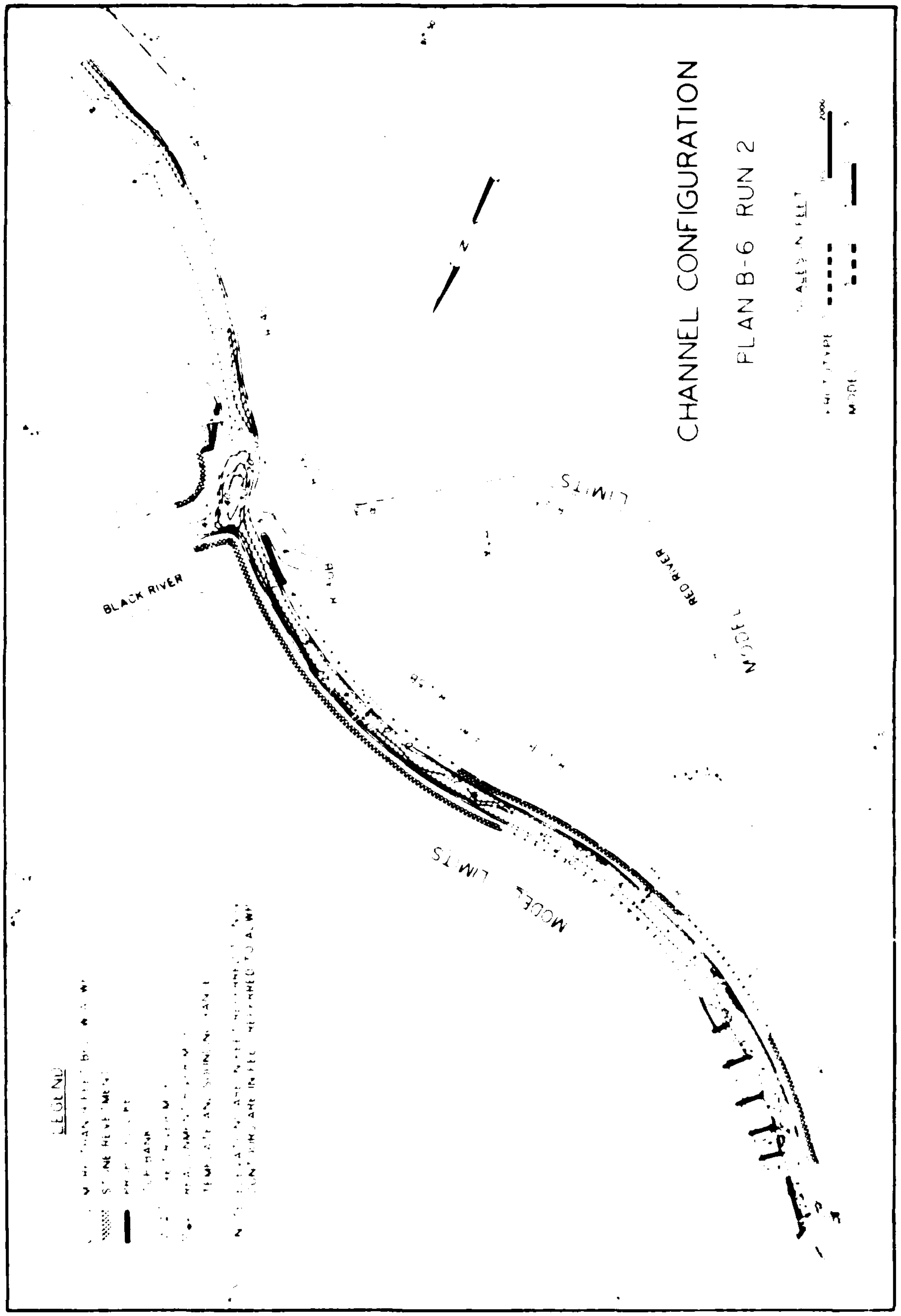

CHANNEL CONFIGURATION
PLAN A-12 RUN 2
SCALES IN FEET
PROTOTYPE
MODEL
LEGEND
STONE REVETMENT
TOP BANK
TEMPLATE AND SOUNDING RANGE
CONTOURS ARE IN FEET REFERRED TO ALWP
BLACK RIVER
RED RIVER
MODEL
LIMITS
MODEL
LIMITS
R-45
R-40
R-35
R-30A
R-25
R-25A
R-20A
R-20
R-15A

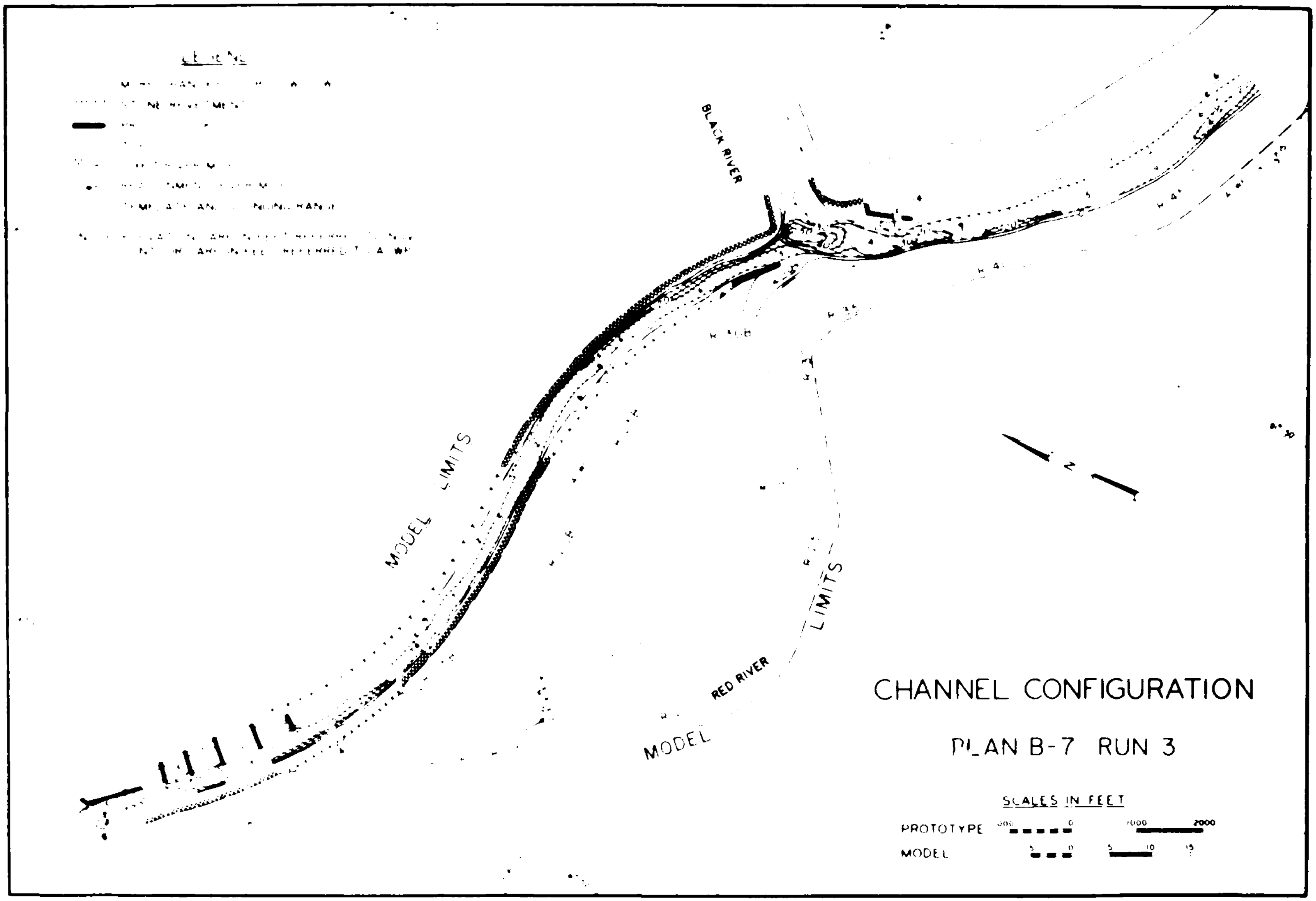

CHANNEL CONFIGURATION
PLAN A-12 RUN 3
SCALES IN FEET
PROTOTYPE
MODEL
BLACK RIVER
RED RIVER
MODEL LIMITS
MODEL LIMITS
LEGEND
STONE REVETMENT
TOP BANK
TEMPLATE AND SOUNDING RANGE

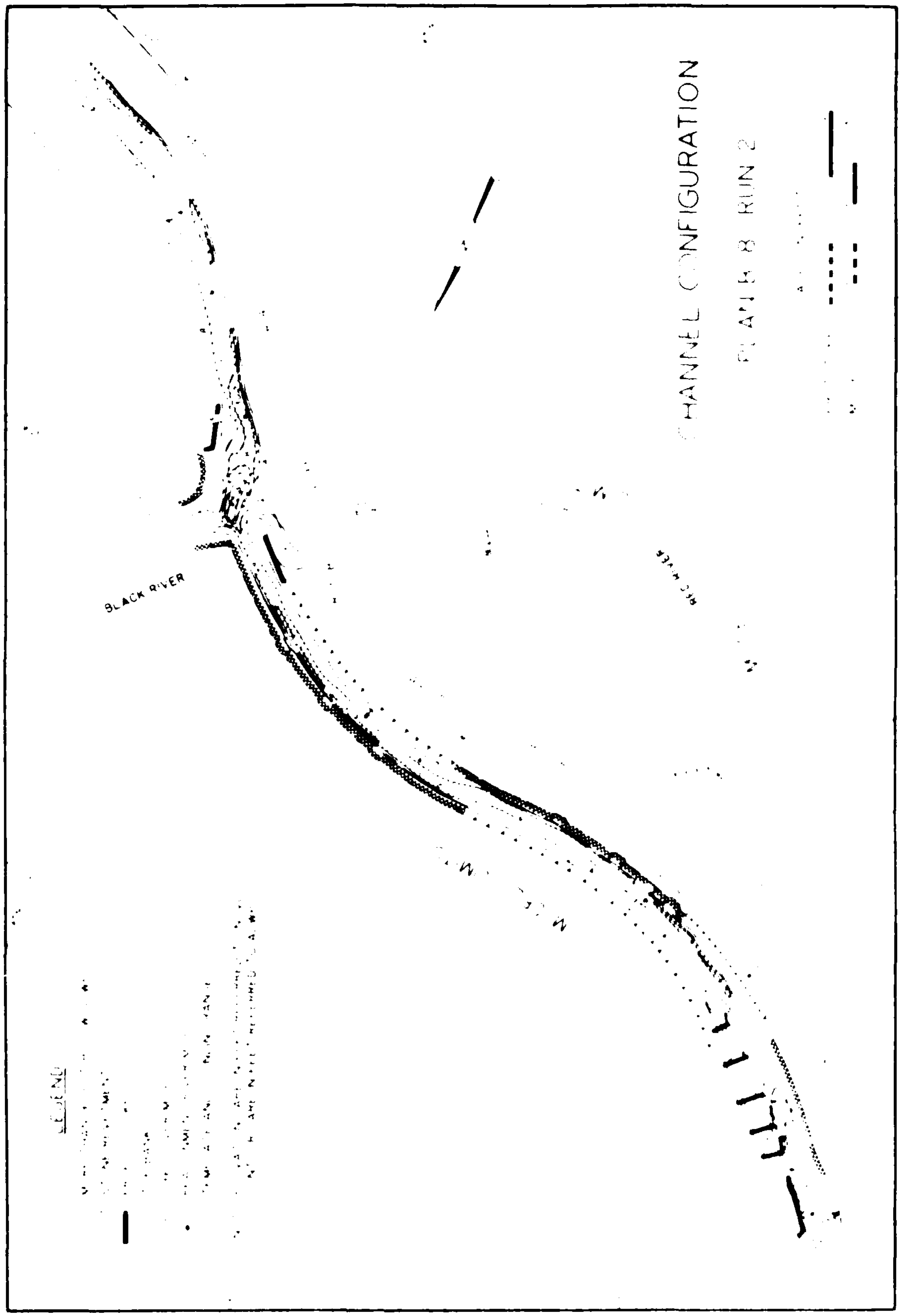

CHANNEL CONFIGURATION
PLAN B RUN 2
BLACK RIVER
RED RIVER
MODEL LIMITS
MODEL LIMITS
LEGEND


CHANNEL CONFIGURATION
PLAN B-2 RUN 2
BLACK RIVER
RED RIVER
MODEL LIMITS
MODEL LIMITS
LEGEND


LEGEND
STONE REVETMENT
TEMPLATE AND SOUNDING RANGE
BLACK RIVER
RED RIVER
MODEL LIMITS
MODEL LIMITS
CHANNEL CONFIGURATION
PLAN B-5
SCALES IN FEET
PROTOTYPE
MODEL


CHANNEL CONFIGURATION
PLAN B-6 RUN 2
BLACK RIVER
RED RIVER
MODEL LIMITS
MODEL LIMITS
LEGEND


BLACK RIVER
MODEL LIMITS
RED RIVER
MODEL LIMITS
N
CHANNEL CONFIGURATION
PLAN B-7 RUN 3
SCALES IN FEET
PROTOTYPE
MODEL


CHANNEL CONFIGURATION
PLAN B-8 RUN 2
BLACK RIVER
LEGEND

END
8-87
DTIC